Human Factors in Long-Duration Spaceflight

NATIONAL ACADEMY OF SCIENCES

Human Factors in Long-Duration Spaceflight

SPACE SCIENCE BOARD
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NATIONAL RESEARCH COUNCIL

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The members of the study committee were selected for their individual scholarly competence and judgment, with due consideration for the balance and breadth of disciplines. Responsibility for all aspects of this report rests with the study committee, to whom we express our sincere appreciation.

Although the reports of our study committees are not submitted for approval to the Academy membership nor to the Council, each report is reviewed by a second group of scientists according to procedures established and monitored by the Academy's Report Review Committee. Such reviews are intended to determine, *inter alia*, whether the major questions and relevant points of view have been addressed and whether the reported findings, conclusions, and recommendations arose from the available data and information. Distribution of the report is permitted only after satisfactory completion of this review process.

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Preface

At the request of the National Aeronautics and Space Administration, the Space Science Board undertook a study of the behavioral, psychological, physiological, and medical factors of manned space missions of up to two years' duration. The Study was organized and conducted under the chairmanship of Donald B. Lindsley, with the assistance of a Steering Committee. Following briefings and planning meetings in 1967–1968, the Committee surveyed the many interlocking factors involved in long-duration missions and identified those specialists most qualified to write on them. The invited papers were completed in 1970 and then were incorporated into the nine topical chapters of this report by the Steering Committee. The Study's major recommendations are contained in Chapter 1; these are supplemented by more specific recommendations at the end of each chapter.

We are grateful to all who participated in the Study and acknowledge with appreciation the support of the National Aeronautics and Space Administration.

CHARLES H. TOWNES, *Chairman*
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Contents

Introduction

The space age began on October 4, 1957, when the Soviet Union put the first earth-orbiting vehicle, Sputnik 1, into space. The United States followed with Explorer 1 on February 1, 1958. A spirit of competition dominated the early years, with investment of national pride and international reputation, rapidly mounting scientific goals, and the will to explore the unknown. Substantial engineering and technological achievements were required to convey even a small object into earth orbit, and even greater advances were required to propel, guide, and control a space vehicle capable of projecting man into space and returning him safely. In addition to heat and radiation shielding, numerous life-support devices had to be created and tested; hardware and procedures had to be perfected for launch, flight, and recovery before human life could be risked even in suborbital flight.

Many unmanned satellites and test vehicles were launched during the following few years. In general, the Soviet Union, with initially greater launch-vehicle capacity, concentrated on larger and heavier payloads and on probes deeper into space. The United States, with less launch-vehicle capacity, concentrated on smaller payloads and sought a variety of data on the upper atmosphere and space. Many engineering and scientific data important to future manned missions were gathered by both countries. Among these were animal flights.

ANIMAL FLIGHTS

As in the case of many medical discoveries of the past, tribute must be paid to the role of animals in the pretesting of human life-support provisions during flight as well as during launch and recovery of the space vehicle. Almost a decade before the first satellites, the Aeromedical Research Laboratory of the Holloman Air Force Base in New Mexico conducted what may have been the first successful animal experimentation in space. The monkey, Albert 2, was lofted 83 mi above earth in a V-2 rocket on June 14, 1949. His heart rate, blood pressure, and respiratory rate were monitored, and although he survived the flight, the space vehicle's parachute failed to open on landing, and he died on impact. Several animals, including a monkey, survived a flight to an altitude of over 44 mi in an Aerobee rocket on September 20, 1951, and were recovered alive, although the monkey died of heat prostration and shock shortly after recovery. On May 21, 1952, two monkeys became the first primates to reach the upper extremes of the earth's atmosphere in tests of the effects of reduced gravity and, together with mice exposed to cosmic radiation, survived the experience without significant aftereffects.

The Soviet Union also carried out animal tests in rockets with parachute recovery during the late 1940's and the 1950's, utilizing dogs trained by Pavlovian conditioning methods. On November 3, 1957, the dog Laika became the first animal to orbit the earth in a protective environmental capsule aboard Sputnik 2. Telemetered data proved that life in space was possible, but Laika was sacrificed after a few days when the capsule's life-support facilities were exhausted. No provision had been made for the recovery of the satellite, and it remained in orbit until decay on April 14, 1958.

The United States, after a considerable lapse in successful animal flights, while preparing for manned Mercury missions, sent the rhesus monkey, Able, and the squirrel monkey, Baker, into space to an altitude of 300 mi in a 1500-mi trajectory in an Army Jupiter intermediate-range ballistic missile on May 28, 1958. They were recovered alive after having attained a speed of 10,000 mph and demonstrated that a species close to man could survive a high rate of acceleration as well as a brief period of weightlessness.

As another prelude to the manned Mercury suborbital flights soon to follow, the monkey, Sam, was lofted from Wallops Island, Virginia, on December 4, 1959, to an altitude of 53 mi. He survived without ill effects despite a rough landing and 6 h of tossing in the Atlantic

Ocean before recovery. On January 20, 1960, Miss Sam, another monkey, safely survived high-*g* loads in a low-altitude flight to 48,900 ft in a successful test of the Mercury-launched parachute escape system.

The Russian dogs, Strelka and Belka, were launched into orbit with Sputnik 5 on August 19, 1960, and their performance in flight was telemetered and observed via television camera during a trip that lasted for 18 earth orbits. They were safely recovered and later bore litters of healthy puppies. In conjunction with this and other flights in 1960–1961, including Sputnik 6 which contained 2 dogs, 2 guinea pigs, 2 rats, 26 mice, fruit flies, seeds, and other biological materials, the Soviet Union pursued an intensive program to determine the effects of the space environment on living things. The dog, Chernuska, was carried in Sputnik 9 on March 9, 1961, and the dog, Zvezdochka, in Sputnik 10 on March 25, 1961. Both these flights were considered successful pretests of the Vostok-type vehicle, which was the first to carry man into space.

The United States put the chimpanzee, Ham, aloft for 16 min in a successful pre-Mercury, suborbital capsule test on January 31, 1961. On November 29, 1961, the monkey, Enos, was successfully flown in a Mercury-Orbital space-systems test.

The importance of these preliminary animal flights and experiments is stressed because they played a significant role in safeguarding man's initial ascent into space. Likewise, the testing of the effects of lowered gravity, radiation, vibration, and numerous other factors upon other living organisms and the testing of life-support and automatic-control features of the spacecraft were essential to the manned missions that were to follow.

Still later, after the first manned missions, as a test for extended duration in space, the Soviet Union successfully orbited the dogs, Ugolyek and Veterok, for 23 days in Cosmos 110, launched on February 22, 1966, and recovered on March 16.

In 1966, the United States began a series of long-delayed Biosatellite flights. Six had been projected, but only three were flown before the program was canceled. Biosatellites 1 and 2 were concerned with fundamental biology, including the effects of weightlessness and radiation on plant and animal growth, genetic processes, and other cellular and biochemical changes. Biosatellite 1, launched December 14, 1966, whose experimentation apparently went according to schedule, was not recovered due to failure of retrofire during re-entry. Biosatellite 2, launched September 7, 1967, was recovered on September 9, one day short of schedule, because of impending earth weather conditions. Although it made only 30 of the 46 planned orbits, it provided valuable data on basic questions in space biology. These, however, were only indirectly relevant to manned flights.

On June 28, 1969, a male nemestrina monkey named Bonny was launched into earth orbit in Biosatellite 3. The flight was planned to answer some of the basic physiological, biochemical, neurological, and behavioral questions about longer-duration spaceflight. The animal was thoroughly instrumented, and about 30 channels of telemetered biological data included recordings of cortical and deep-brain electrical activity, electrooculograms, electrocardiograms, electromyograms, brain and visceral temperatures, and respiratory and cardiovascular functions. Provision was also made for biochemical and behavioral measurements and for monitoring changes in the capsule environment. These were the most comprehensive recordings and measurements ever attempted on a living organism in space. Bonny remained in orbit for nearly nine days when, because of progressive signs of deterioration from about the seventh day, he was brought down and recovered. He died about 12 h after deorbit. Various perturbations were noted in physiological and behavioral functions during the flight, including disturbances in the sleep–wakefulness cycle, desynchronization of various circadian rhythms, decrease of body and brain temperatures, loss of fluid, increase of central venous pressure, and other physiological changes (see "Biosatellite III Results," *Aerospace Med.* 42:271–336, 1971). Whether these significant changes were primarily associated with weightlessness or with other stresses is under debate (see, for example, "The Future of the Bioscience Program," Hearings before the House Subcommittee on Space Science and Applications, Nov. 1969, U.S. Govt. Printing Office, Washington, D.C., 1970, pp. 71–184).

In some respects the data from the Bonny experiment seem to be in accord with fragmentary reports of difficulties encountered or suspected in manned flights. Yet, as previously mentioned, the Russian dogs on the Cosmos 110 flight survived for 23 days in earth orbit, presumably without difficulty. Also, both before and after the Bonny flight, Gemini earth-orbiting and Apollo lunar missions of up to 14 days were accomplished successfully and apparently without lasting detriment to the astronauts. An 18-day stay in space by two Soviet cosmonauts on the earth-orbiting flight of Soyuz 9 was, it seems, without mishap or serious consequence, but Soviet physiologists associated with the flight presented cautionary reports at the 1971 COSPAR meeting (*Life Sciences and Space Research*, Vol. 10, in press). Subsequently, in 1971, three cosmonauts in Soyuz 11 accomplished 24 days in space, although the flight ended tragically on re-entry because of equipment failure. (It should be emphasized that the evaluative comments about these and other missions pertain mainly to "mission success" rather than to perturbations and other difficulties encountered in flight or afterward.)

It is unfortunate that the Bonny experiment could not have continued for the full 30-day mission as planned. Had Bonny's condition not made it advisable to terminate the flight prematurely, it is possible that the data obtained during a 30-day period of weightlessness would have much enhanced the predictive basis for the safety, or lack of it, of man on longer-duration missions.

Some scientists believe that it is impracticable to conduct Bonny-type experiments over long durations in space without a human observer or experimenter in attendance to care for and monitor the status of the animal and to make necessary adjustments of the equipment. They are dubious about automated or semiautomated and ground-controlled experiments on higher animals in space. In any case, since no further experiments of this type are scheduled, it appears that the opportunity for further U.S. flight data on higher animals will have to await Skylab-type missions or the development of space stations some years hence.

The most recent animal flight (November 1970) was the Orbiting Frog Otolith experiment to study the activity of single vestibular gravity receptors at very low *g*. The time course of the adaptability curves during the 6-day orbital flight indicated that the vestibular organs adapted, or would adapt, to weightlessness in 6 to 12 days—a remarkable finding given that terrestrial animals have never had exposure to weightlessness throughout evolution. In view of the fact that these results are based on a single flight of two animals, it would be prudent to have additional data before concluding that man's vestibular apparatus will always adapt to weightlessness.

MANNED FLIGHTS

The first manned spaceflight was made by the Soviet Union when Yuri Gagarin was put into orbit in Vostok 1 on April 12, 1961, and returned safely on the same day. This was followed by Gherman Titov in Vostok 2 on August 6. In the meantime, the first U.S. manned suborbital flight lasting 15 min was made by Alan B. Shepard, Jr., in the Mercury capsule *Freedom* 7 on May 5, 1961. Another suborbital flight of the same duration was made by Virgil I. Grissom in Mercury capsule *Liberty Bell* 7 on July 21, 1961.

The first U.S. manned earth-orbiting flight was made by John H. Glenn, Jr., in Mercury *Friendship* 7 on February 20, 1962. Three orbits were made, lasting 4 h, 55 min. This was followed on May 24, 1962, by the flight of *Aurora* 7 with astronaut M. Scott Carpenter on board; again three orbits were made, lasting 4 h, 56 min. Still later, on October 3, 1962, Walter M. Schirra made six orbits of the earth, lasting 9 h, 13 min, in *Sigma* 7. The last of the Mercury flights was made by L. Gordon Cooper in *Faith* 7 on May 15, 1963. After 22 earth orbits lasting 34 h, 20 min in space he returned safely on May 16. The one-man Mercury flights ranging from 15 min in suborbital flight to nearly 35 h in earth orbit demonstrated that man could tolerate both the high-*g* loads of lift-off and re-entry and several hours of weightlessness without apparent ill effect. The two-man Gemini series which followed gradually increased the duration in space to 14 days; the early earth-orbiting Apollo missions provided for three astronauts and flight durations to meet lunar orbiting and landing requirements.

In the meantime, the Soviet Union launched Vostoks 3 and 4 on successive days, August 11 and 12, 1962, with cosmonauts Andrian G. Nikolayev and P. Popovich on board; both returned on August 15 after three and four days aloft. Vostoks 5 and 6 carried Valery F. Bykovsky and the first female cosmonaut, Valentina V. Tereshkova, on June 14 and 16, 1963; both returned safely on June 19 after five and three days aloft, respectively. These were attempts to practice rendezvous and docking maneuvers in space, but, at the same time, they increased the length of man's stay in space.

Next, the Soviet Union launched the first three-manned spacecraft, Voskhod 1, with cosmonauts Vladimir M. Komarov, Konstantin P. Feoktistov, and Boris B. Yegorov on board, on October 12, 1964. The first extravehicular activity (EVA) was performed by cosmonauts Pavel I. Belyayev and Aleksey Leonov from Voskhod 2, launched March 18 and returned to earth on March 19, 1965.

The United States put its first two-man crew aloft March 23, 1965, and Virgil I. Grissom and John W. Young performed the first orbital maneuvers in space in Gemini 3. On June 3, 1965, Gemini 4 was launched with astronauts James A. McDivitt and Edward H. White; they orbited the earth 62 times and performed the first U.S. EVA maneuvers. Gemini 5, launched August 21, 1965, with L. Gordon Cooper, Jr., and Charles Conrad, Jr., on board, stayed up eight days, thus demonstrating the feasibility of flights of the duration of lunar missions. Gemini 7 was launched December 4, 1965, with Frank Borman and James A. Lovell, Jr., as its astronauts. It remained aloft for 14 days and was the target for a successful rendezvous with Gemini 6A, manned by Walter M. Schirra, Jr., and Thomas P. Stafford, which was launched on December 15, 1965. Gemini 7 held the duration-aloft record until it was broken by an 18-day mission of Soyuz 9, manned by Andrian G. Nikolayev and Vitaly I. Sevastyanov in June 1970. Gemini 7 was a notable mission in other ways for it provided the first extensive physiological measurements on man by the United States during a prolonged flight. As will be brought out later, these measurements, though valuable, were very limited and came quite late in a flight program that had gradually extended man's stay in space from a few minutes to several days.

We have seen how, step by step, empirical determinations of safety and feasibility were made from first suborbital and then orbital missions of longer and longer duration, up to 14 days for the United States in Gemini 7 and recently (June 1971) up to 24 days for the Soviet Union in Soyuz 11. Among other things, the Soviet Union had as a predetermined control for their extended-duration flights the fact that the dogs Ugolyek and Veterok had successfully sustained themselves for 23 days in earth orbit in Cosmos 110. In addition, they had the results from progressively extended manned flights. It appears also that they had conducted moderately extensive physiological and other measurements in ground simulation studies as well as in flight. The U.S. program, in which engineering problems and mission goals held top priority and which relied primarily on a conservative incremental approach of progressively longer flights, had mainly the knowledge that man had survived, apparently without detriment to health. Flight-recorded or telemetered physiological data included respiration, heart rate, blood pressure, and electroencephalographic recordings obtained during Gemini 5 and 7, heart rate and respiration on all manned flights, and extensive preflight and postflight assessments on all missions. Indirectly, other data provided some assurances since astronauts were ground-tested in all procedures with all systems in operation prior to each flight. Also unmanned, manned, or animal missions were sent aloft to test the functioning of each life-support system in earth orbit as well as to test launch and recovery procedures. The accumulated evidence, up to the anticipated maximal duration for Apollo missions to follow, was favorable and provided a not unreasonable basis for moving ahead. However, when the incremental approach is not supplemented with extensive inflight biomedical monitoring, it has limitations and exceptions. First, the flights were not deep-space probes such as a lunar orbiting or landing mission and therefore could not predict with certainty what difficulties might be encountered by man physically, physiologically, or psychologically under those conditions. Second, insufficient biochemical, physiological, behavioral, and functional performance tests had been made on man and animals in flight so that there was little scientific evidence available for assuring satisfactory performance of man on the mission, health and integrity of his bodily and central-nervous-system functions in flight, or his health and status over time following the mission. In calling attention to these deficiencies, one should not lose sight of the dedicated efforts of the many individuals within and outside the space agency to place the biomedical program on an increasingly sound footing.

Early in 1967 disaster struck both the U.S. and Soviet manned programs. In a prelaunch simulation on January 27, 1967, fire broke out in the command module of Apollo 204, intended to become Apollo 4, the first Apollo manned earth-orbiting test mission. Astronauts Virgil I. Grissom, Edward H. White II, and Robert B. Chaffee were unable to release the escape hatch and perished. The exact cause of the fire remains undetermined, but the 100-percent oxygen environment under 16 psi was a contributing factor. This hazard was subsequently lessened by initiating a 60–40 percent oxygen–nitrogen mixture at liftoff. The disaster experienced by the Soviet Union was the loss of cosmonaut Vladimir M. Komarow, who, after a successful flight in Soyuz 1 launched on April 23, 1967, was killed on re-entry on April 24. These tragic accidents caused postponement of further U.S. and Soviet manned flights until remedial measures had been taken.

Apollo flights 4, 5, and 6 were unmanned test flights. Apollo 7, the first manned Apollo flight, carried astronauts Walter M. Schirra, Jr., Donn F. Eisele, and Walter Cunningham into earth orbit on October 11, 1968, returning safely on October 22. The astronauts developed colds in flight but successfully completed their mission which included rendezvous maneuvers with the separated S-IVB stage and other tests of the vehicle's propulsion system. Apollo 8, the first manned lunar mission, was launched on December 21, 1968. It carried astronauts Frank Borman, James A. Lovell, Jr., and William A. Anders on 10 orbits of the moon. The mission duration was 6 days, 3 h. Apollo 9, with James A. McDivitt, David R. Scott, and Russell Schweickart, was launched into earth orbit on March 3, 1969, and returned March 13 having spent a little over 10 days in space practicing all elements of maneuvering, release, and recovery of the lunar module and EVA activities. Apollo 10, crewed by astronauts Eugene A. Cernan, John W. Young, and Thomas P. Stafford, was launched on May 18, 1969, on an 8-day mission which included 31 orbits of the moon. The lunar module was lowered to within 50,000 ft of the moon's surface and then returned its occupants to the command module.

In the meantime, the Soviet Union sent Soyuz 2 aloft unmanned on October 25, 1968, as a target for Soyuz 3, manned by cosmonaut Georgy T. Beregovoy and launched on October 26, 1968. Rendezvous was accomplished, and Soyuz 2 re-entered October 28; Soyuz 3 returned on October 30.

Probably the most famous and significant event of the space age to date was the flight of Apollo 11 on July 16, 1969, which accomplished the first landing of man on the moon. On July 20,1969, astronauts Neil A. Armstrong and Edwin E. Aldrin, Jr., descended in the lunar module, *Eagle,* to the surface of the moon, while astronaut Michael Collins flew the command module, *Columbia,* in lunar orbit until the moon explorers returned in *Eagle* to join him for the return to earth on July 24.

In October 1969, the Soviet Union placed seven cosmonauts in space at one time in three different spacecraft, presumably for the purpose of rendezvous and maneuvering and possibly with the aim of preparing for the construction of a space station. On October 11, 1969, Soyuz 6 was launched with cosmonauts Georgy S. Shonin and Valery N. Kubasov; on October 12 Soyuz 7 carried cosmonauts Anatoly V. Filipchenko, Viktor V. Gorbatko, and Vladislav N. Volkov; on October 13 Soyuz 8 followed with cosmonauts Vladimir A. Shatalov and Aleksey S. Yeliseyev. These spacecraft returned safely on October 16, 17, and 18.

The second lunar landing was made by astronauts Charles Conrad, Jr., and Alan L. Bean on November 19, 1969, while Richard F. Gordon, Jr., piloted the Apollo 12 command module in moon orbit. The Apollo 12 lift-off occurred on November 14, and recovery was made on November 24. Total flight time was 10 days, 4½ h; total EVA time on the moon was 15½ h. Apollo 13 was launched April 11, 1970, with astronauts James A. Lovell, Jr., Fred W. Haise, Jr., and John L. Swigert on board. It was to be another attempt to land on the moon, but because of rupture of an oxygen tank en route the mission was aborted after 56 h. Magnificent performance by the flight crew and Mission Control brought the Apollo 13 capsule safely back to earth after a total flight time of approximately 143 h.

On January 31, 1971, Apollo 14 was launched toward the moon with Allen B. Shepard, Jr., Edgar D. Mitchell, and Stuart A. Roosa as its astronauts. While Roosa piloted the command module *Kitty Hawk*, Shepard and Mitchell descended to the surface of the moon in the lunar module *Antares* and spent 33½ h exploring and gathering rock samples. Apollo 14 was recovered on February 9 after about 10 days in space.

In the interim, the Soviet Union continued its earth-orbital work with Soyuz 9, carrying cosmonauts Andrian G. Nikolayev and Vitaly I. Sevastyanov on a record-breaking 18-day flight, June 2–19, 1970. Gemini 7, the preceding record holder, and Soyuz were particularly important flights not only because of their extended durations but because more effort was devoted to physiological and other measurements in flight and to preflight and postflight testing. Summaries of U.S. data on Gemini and Apollo missions (see *Aerospace Med.* 40: 762, 1969; 41:500, 1970) and Soviet reports of Soyuz flights (see especially reports on Soyuz 9 by Kakurin *et al.* and Nefyodov *et al.* in *Life Science and Space Research*, Vol. 10, in press) agree that changes have occurred in skeletomuscular, neuromuscular, and cardiovascular systems and in other physiological and biochemical processes. These changes, of both static and dynamic nature, are of sufficient magnitude, persistence, and consistency to raise warnings and to call for more intensive inflight and ground-based study of these problems. Very little systematic and sophisticated observation and study of behavioral, psychological, and sociopsychological factors have been carried out or even discussed, as these affect health, well-being, performance, and the likelihood of mission success, especially on long-duration missions. For this reason, considerable attention is given in this report to these factors.

In particular, Soyuz 9 revealed significant changes in several physiological systems, especially the neuromuscular, cardiovascular, and central nervous systems. Adaptation times during the flight and re-adaptation to gravity postflight were studied. In addition to loss of body weight and fluid volume, there was loss of muscle mass, body weakness and asthenia, muscle pain and increased pain sensitivity, hyperreflexia, and dizziness and instability in vertical posture. Some symptoms developed early in flight and showed adjustment after several days, others developed only after about 13 days, and still others were observed only upon return to the earth environment and persisted for

10 days or more. Readjustment to earth gravity was particularly stressful and distressing and led to the conclusion that the recovery phase following longer flights would require much further study. One outcome of this flight was an intensive effort to develop compensatory procedures and devices to combat muscle atrophy and loss of muscle tone, as well as cardiovascular decompensation, by pressure fittings and supports and by a rigid regimen of exercises during flight. These modifications were put into effect on the Soyuz 11 flight which, despite its tragic ending, presumably telemetered or returned extensive data important to the solution of some of these problems.

Evidently as a prelude to the Soyuz 11 mission, Soyuz 10 was lofted into earth orbit on April 22, 1971, to rendezvous with the 25-ton space station, Salyut, which was sent aloft on April 19. Soyuz 10 carried cosmonauts Vladimir Shatalov, Aleksey Yeliseyev, and Nikolai Rukavishnikov. After 5½ h of docking maneuvers with Salyut it returned to earth on April 25.

The longest manned flight to date ended tragically on June 30, 1971. The three cosmonauts of Soyuz 11, Georgy T. Dobrovolsky, Vladislav N. Volkov, and Viktor I. Patsayev, died shortly before reentry when their capsule depressurized because of a faulty hatch. Available information indicates that the 24-day flight, which began on June 6, was a successful mission in that the crew made rendezvous with, and entered, the unmanned Salyut on June 7 for the longest stay in earth orbit yet experienced. This represented a new phase in manned spaceflight—development of the permanent space station. Numerous biological, botanical, and medical experiments were conducted, and major emphasis was given to investigations into deconditioning and vestibular effects. According to Soviet sources, the cosmonauts' health underwent no significant changes during the flight. Interestingly, the cosmonauts followed a regime of systematic exercises from 2½ to 4 h each day in orbit.

The most recent flight, Apollo 15, was launched on July 26, 1971, with David R. Scott, James B. Irwin, and Alfred M. Worden on board. On July 30, astronauts Scott and Irwin descended in the lunar module *Falcon* to the moon's surface and spent 67 h exploring and collecting samples, utilizing the lunar Rover. After concluding their noteworthy scientific mission on the moon, they rejoined the moon-orbiting spaceship *Endeavour* piloted by Worden, who in the meantime had photographed much of the moon's surface, for a safe splashdown in the Pacific after 12 days in space. Among the experiments carried out during the flight was one particularly relevant to this study. Wearing black eye-shields, the astronauts observed 61 light flashes during an hour-long test in flight beyond the earth's magnetosphere. Frequently reported by previous spacemen, these flashes are believed to result from the impact of high-energy heavy cosmic rays on the retina, the visual pathways, or the visual cortex. Further evidence along these lines has been obtained from studies of the helmets of Apollo 8 and 12 astronauts (Comstock *et al.*, *Science* 172:154–156, 1971), where density and track formation of heavy cosmic-ray nuclei have been detected and studied quantitatively. By extrapolating from the duration of exposure on these missions to missions of 2-year duration, it is estimated that small, but possibly highly significant, numbers of cells might be affected in the retina and various brain structures. Tracklike lesions have been reported (Haymaker *et al.*, *Aerospace Med.* 41:989, 1970) in the brains of monkeys exposed to primary cosmic rays. Thus these heavy particles must be studied further with respect to the potential damage they could cause on long-duration flights, and ways must be sought to circumvent this if possible.

FUTURE MANNED SPACEFLIGHT

There has been much speculation about the future role of man in space. The question has often arisen whether unmanned vehicles under ground control are not more economical and effective in the hostile space environment. Yet, the experience of the past decade suggests that the man–machine combination can function more effectively than machine alone in certain scientific missions. Thus far, with respect to lunar exploration and the gathering of lunar samples, it appears that much more has been accomplished by the manned lunar landers than by the unmanned ones, for example, the Soviet Luna 16. The November 1970 landing by the Soviet Union of a robotlike moonwalker (Lunakhod 1) from Luna 17 provides some hope that a ground-controlled vehicle relatively immune from the hostile environment and capable of moving about to collect and even analyze samples may supplant man on lunar and other more distant missions. Nevertheless, there still seems to be a feeling that man will eventually be used on long-duration missions to the planets, and that with the coming of space stations and space laboratories in earth orbit for prolonged periods of time, with space shuttles to convey men back and forth for periods of service up to at least six months, man will find much opportunity to live and work in space and to perform a great variety of meaningful physical and biological experimentation.

Therefore, the questions that arose in 1967 and led to the request that the present study be made of the problems to be encountered by man on long-duration space missions seem to be as real and valid now as they were then. Perhaps more so, for, although man has successfully endured up to 24 days in space, some persons believe that this period may be approaching his duration-threshold of tolerance for weightlessness, physiological and psychological stress, and maybe the onset of performance deterioration. Others disagree, and the evidence is contradictory. For example, despite more preparatory ground and flight experimentation by the Soviet Union and deliberate efforts to precondition cosmonauts Nikolayev and Sevastyanov for their 18-day mission in Soyuz 9, these cosmonauts reported in subsequent talks before the American Institute of Aeronautics and Astronautics that they had profound disturbances in sleeping, walking, and standing for about 10 days after they returned to earth. They lost weight, muscle mass, and strength during the flight. On the other hand, one would conclude from press reports on the Soyuz 11 cosmonauts that their health and performance were unimpaired after 24 days. Both American astronauts and Soviet cosmonauts have been reported in the past to have suffered fluid loss and dehydration, loss of bone calcium, some desynchronization of circadian rhythms, development of tachycardia on exertion, and other physiological and biochemical changes, but it is not clear whether these changes represent an adjustment to the conditions of spaceflight and reach a steady state or whether they progress with time in space. Although none of these symptoms appears to have interfered with the performance of the astronuats or to have left them with any serious or lasting aftereffects, some slips or mishaps have occurred which might have been due as much to human error as to mechanical failure. For example, cameras have failed to work properly, docking procedures have proved difficult at times, and other events no doubt have occurred that might have led to errors had not ground-controlled backup been monitoring almost every move. Again, the reverse has often been apparent, as in the superb performance of the Apollo 13 crew in bringing back safely their crippled craft.

The first decade of manned spaceflight has brought stunning successes in man's exploration of the unknown and a basis for contemplating ever more ambitious enterprises into space. But man's ability to tolerate the space environment for long durations–for, say, one or two years–is by no means apparent from the data accumulated thus far. Some of these data are encouraging, others suggest potential dangers, but from all, one fact stands out: if, indeed, the long-duration mission is possible, it will not be easy for man. In addition, it will require years of concentrated research on the ground and in-flight, into physiological and biochemical factors, behavioral and performance factors, and social interaction factors under spaceflight conditions. But two developing trends are especially encouraging: the increasingly high priority being given to biomedical and human-factors research in the remaining Apollo flights and Skylab and the efforts by the Soviet Union and the United States toward greater cooperation and exchange of biomedical information from manned and unmanned flights. These must surely lead to a more systematic appraisal of possible perturbations and difficulties occasioned by longer-duration flights and to solutions to these problems which would help to ensure the safety of astronauts and cosmonauts and, in general, advance the exploration of outer space for the benefit of all mankind.

DONALD B. LINDSLEY, *Chairman*
Long-Duration Missions Study

1 Summary and Major Recommendations

This report seeks to assemble and put into initial perspective factors that would bear on man's participation in spaceflights of one- to two-year duration. Its objective is to assess, insofar as present knowledge permits, whether man's participation is possible and feasible and to identify major obstacles and unknowns that must be resolved. It is not the purpose of this report to evaluate whether man *ought* to engage in missions of long duration if he is physically and psychologically able to do so.

The intent of the recommendations in this report is to indicate the blocks of research, roughly in order of priority, that will be most fruitful in the years ahead in coming to grips with the problems of long-duration missions. In this, there is little doubt in the minds of the study participants that the difficulties are formidable, the unknowns significant, and the prerequisite research extensive in subject matter and in time needed for completion.

The types of mission in question are intentionally not specified, despite the fact that the goals or destinations of particular missions will clearly affect the human factors involved. For example, one or two years in an earth-orbiting space station (unlikely, given opportunities for crew rotation, but not inconceivable) would be characterized by relatively spacious living conditions and comparative freedom from threat because of rescue capabilities. A planetary flyby or landing, requiring at least two years, would be far more cramped and stressful, no rescue or recall would be possible during most of the voyage, and illness or intolerable friction among crew members could not be remedied by exchanging personnel. Manning a lunar base would have the very different element of one-sixth gravity rather than weightlessness. These three types of mission would entail differing scientific and operational tasks. To emphasize such differences would be to obscure the central similarities that will likely govern whether men should participate in long-duration spaceflights. The similarities include: (a) the environment of space in which man cannot survive unless encapsulated in his own life-support system—unique components of the environment include weightlessness, high vacuum, and radiations not normally encountered on earth; (b) confinement in a spacecraft of a few persons for up to two years—the crew members must depend on the proper functioning of the spacecraft and on each other for physiological, professional, and social support; (c) isolation from family, friends, and the outside world except for vocal communication with ground control.

The following chapters attempt to visualize some of the many elements that would be brought to bear on man under these circumstances and to determine physiological and psychological influences. Because manned spaceflights to date have been of short duration, and because inflight biomedical and behavioral measurements have been few, analogies are sought in the literature. Studies of isolation and confinement, and of spaceflight simulations, are drawn on most heavily. The last two chapters combine the material presented in the earlier chapters into a social-system model of the capsule environment and a synthesis of operational requirements relative to human factors. A summary of the chapters, followed by the major recommendations of this study, are set forth below. Additional recommendations, not in order of priority, appear at the end of each chapter.

It would be well first to touch on the broader perspective of this study. It will be evident that this report calls for research into a wide range of problems, from bioinstrumentation and automated physical examinations to small-group dynamics, development of objective performance tests, criteria of habitability, relation between brain waves and cognitive efficiency, and so forth. Some of these problems are difficult to solve; some have only recently been recognized. Others have been recognized for a long time, but solutions were not pressing as they did not impinge critically on research advances, spaceflight, or society. Many of the latter problems are critical for long-duration spaceflight, and some have important bearing on pressing social problems. What constitutes habitability and how it can be provided in optimal fashion in the face of increasing population pressures on limited space are of very real interest to the individual apartment dweller, housing authorities, and industrial organizations. The high cost of medical care and shortage of doctors combined with ever-rising expectations of excellent and innovative medical care encourage the search for alternative methods including automated techniques. The dynamics of small groups and the factors that favor or discourage cooperative work are of increasing import to corporations and schools as well as to communities and families. New biofeedback techniques that permit the individual to learn to influence his brain waves—and other voluntary and involuntary processes—give practical importance to the understanding of brain mechanisms that hitherto may have seemed of purely academic interest. Perhaps it is not necessary to labor this point further. Possibly the central point is that in today's society on earth we are approaching many of the conditions of the crew in a long-duration spaceflight.

SUMMARIES OF CHAPTERS

PHYSIOLOGICAL AND MEDICAL FACTORS

Spaceflight, as practiced thus far and as envisaged for the foreseeable future, is characterized by a physiologically restrictive environment, due especially to weightlessness and relative inactivity. Such an environment leads to altered fluid and electrolyte balances, to general physical deconditioning, and to deconditioning of specific physiological systems, primarily the cardiovascular, musculoskeletal, metabolic, and neuroendocrine systems. On Gemini and Apollo missions ranging up to 14 days, evidence of general and specific deconditioning has been noted in biochemical and physiological measurements and in symptoms reported by astronauts. Deconditioning has not yet, apparently, resulted in deterioration of performance during flight or in persisting impairment of health or behavior postflight. However, if deconditioning should progress with length of stay in space, prolonged flights could lead to performance penalties inflight and possibly to irreversible health hazards, particularly on re-entry into the gravity environment. On the other hand, man's capacity for adaptation, coupled with appropriate countermeasures, may make long-duration missions tolerable. The available evidence is fragmentary and sometimes contradictory; thus far deconditioning has not presented an insurmountable barrier to prolonged space missions. Nevertheless, it is clearly of first importance to determine the limits of deconditioning and to arrive at approaches to understand it as a physiological phenomenon.

High-energy cosmic rays of high atomic number (high-Z particles) are a second possible barrier to long-duration flight beyond the earth's magnetosphere. It is hypothesized that this radiation may have a cumulative effect on nondividing cells, particularly of the central nervous system. Investigation of these effects is in the earliest stages of development.

Space clinical medicine is directed toward preventing the occurrence of medical problems in space and toward restoring to optimal functional capability an astronaut suffering from a medical problem. To date, owing to the brevity of space missions, there has been little justification for providing for management of medical problems in flight. However, the scope and responsibility of clinical medicine will increase as missions enlarge in duration, distance, and complexity and as they require larger crews. To this end, much effort will be spent in coming years in identifying potential hazards that are peculiar to space operations as well as those illnesses that might occur in the natural history of any group of individuals. Development of optimal means for the management of such problems in space is most important.

Prolonged missions presuppose man's ability to perform at a high physical and mental level throughout. It is likely that supportive measures will be necessary to assure this capability, and that these will be based on patient and detailed evaluation of the biomedical status of the crew before and during the flight. The conditions of long-duration missions strongly favor the development of automated, noninterfering monitoring devices. The complexity and subtlety of the biological processes involved require that a great deal of inflight biomedical data must be assembled and analyzed in preparation for such missions. There will be a deep and continuing interplay between broad interdisciplinary teams, drawn from the physical and engineering sciences as much as from biomedical specialties, before these goals in medical measurement can be accomplished.

PHYSICAL FACTORS

During the first decade in space, overwhelming priority has naturally been given to the engineering of the spacecraft itself and to its operational and life-support systems. Provisions for human comfort have been incidental and secondary but have been bearable because of the brevity of the missions. The length and stresses of prolonged spaceflight require that man's needs be given far more attention: human-factors requirements should be incorporated into the basic engineering design. One of these factors relates to man's physical dimensions and to the extent to which the physical features of the spacecraft have been adapted to his needs and comfort. This includes the design and configuration of the interior of the spacecraft for optimal habitability, life support, safety, and operational efficiency. The design and location of operational indicators and controls should be consonant with the dimensions of the crew's bodies, their operating positions and restraints, and the condition of weightlessness. In view of anticipated physiological and psychological problems, provision must be made for exercise and for personal and social adjustment.

SENSORY, PERCEPTUAL, AND MOTOR FACTORS

The ability of astronauts to perform critical tasks reliably and repeatedly for extended periods will depend on the efficiency and accuracy of their sensory, perceptual, and motor processes. Ground-based studies under confinement, isolation, and sensory or perceptual deprivation represent the closest available analogs to the effects that long-duration spaceflight may have on these psychological factors. It must be emphasized that the conditions in these short-duration experimental studies differ in some important respects from those anticipated in long-duration flight, and that extrapolations must be made cautiously. The astronauts will not be completely isolated from, or deprived of, sensory and perceptual experiences. However, there will be restriction, and some deprivation, in the sense that considerably less diversification and variation will be present than in everyday life. Rather more important may be the monotony of repetition of limited kinds of stimulation such as continual background noises produced by the spacecraft, monotony of tactual and temperature sensations, and monotony of olfactory and gustatory experiences.

Studies specifically investigating sensory and perceptual deprivation have encompassed relatively short periods of confinement, isolation, and deprivation ranging from a few hours to 7 days, and in a few instances, 14 days. They have provided varying and contradictory results, perhaps depending upon methodological differences, degree and length of deprivation, motivation of subjects, and other factors. Nevertheless, some studies have revealed, under reasonably well-controlled conditions, certain losses or changes in sensory, perceptual, and perceptual-motor functions if the deprivation is severe and long enough. Among visual functions that may be affected are color discrimination, movement perception, and imagery. Although changes occur in brightness, depth, and form perception, they are either minimal or contradictory, in various studies, and do not permit generalizations. The studies of auditory functioning have not been numerous nor remarkable in their results. Cutaneous and kinesthetic functions have not been markedly affected, but tactual sensitivity has shown more consistent changes than pain and temperature sensitivity. Olfactory and gustatory results are sparse, inconsistent, and appear trivial. Changes in estimation of time have been noted. Effects on perceptual-motor performance, involving particularly speed of reaction and accuracy, are somewhat contradictory and are probably more attributable to levels of motivation, activation, and arousal than to sensory or perceptual deprivation *per se*. Vigilance appears to be affected adversely, probably for similar reasons.

The results of these short-duration studies would suggest that minimal and relatively insignificant changes in sensory and motor function are likely to occur during long-duration missions. Nevertheless, further experimental effort with more reliable and valid assessment is needed before confident predictions can be made.

MOTIVATION, COGNITION, AND SLEEP-WORK FACTORS; CENTRAL- AND AUTONOMIC-NERVOUS-SYSTEM INDICES

Confinement and isolation, with or without sensory deprivation or sensory restriction, usually lead to monotony and boredom, states that are subjectively very stressful. Persons under these conditions usually show reduced motivation for and interest in immediate tasks and even long-term goals. There is a tendency to become more subjectively and personally oriented and thus to become more subject to psychosomatic and psychoneurotic complaints. Persons feel that they have suffered impairment in efficiency and in higher-level intellectual and cognitive functioning. Paradoxically, laboratory studies (all short in duration) have not revealed impairment of performance on tasks involving immediate memory span, vigilance, complex perceptual-motor skills, verbal learning, or sensory acuity; in fact, some of these have shown improvement. The states of consciousness involved here are not clearly understood. Reasonably good physical and mental performances were maintained in a year-long Soviet confinement study simulating a long-duration mission.

Motivation for crew members should not be a problem, at least on the first long flights, and individuals who cannot tolerate long confinement will be eliminated during training. Very little is known, however, about optimal techniques for reducing monotony and boredom during long periods of group confinement or of assuring cognitive efficiency under these conditions.

Perturbations of sleep, disturbances and desynchronizations of sleep–wakefulness cycles and other rhythms, and maladjustment to sleep and work–rest cycles have been noted in short-duration spaceflights, although few measurements and evaluations have been made other than the keeping of informal logs. Similar disturbances among members of an Antarctic wintering-over party have been noted in sleep logs and in electroencephalographic (EEG) data, as well as in reports of malcontent and maladjustment. Changes in the EEG during sleep (different ratios of EEG stages) and wakefulness (slowing of alpha waves) have been observed in persons subjected to confinement and isolation, during laboratory studies of sensory and perceptual deprivation.

Loss of sleep and changes in the "goodness" or quality of sleep are apt to affect critically performances depending on immediate memory, vigilance, and computational and decision-making tasks; problem-solving and logical analysis are more resistant to sleep deprivation. Work-paced monitoring tasks have not been sensitive to isolation and confinement alone but are extremely vulnerable to sleep deprivation.

It appears that cognitive functioning, sleep, and work–rest cycles are areas of potential difficulty in long-duration manned spaceflights.

SKILLED PERFORMANCE

The complex skills and high-level performances required of an astronaut may be difficult to maintain, or retain after long intervals of disuse, during long-duration missions. Parameters affecting skilled performance are complex and interacting; they include (a) components of the physical environment, such as weightlessness and radiation; (b) social–environmental factors resulting from operational demands, compatibility, and loss of sleep; (c) psychophysiological aspects of individual behavior, such as fatigue, diurnal and other cycles, and nutrition; and (d) reactions to severe threat. Extreme deviation in any parameter, or combinations of less extreme variation of many relevant parameters, could result in the degradation of performance to a point that might impair the accomplishment of a mission. Maintenance of proficiency under stress is a goal opposed to the adaptive functions of all physiological and psychological defenses, which may urge the individual to behavioral changes involving control of impulse, abandonment of the task, or at least degradation of performance.

Maintenance of skills and performance should be approached from several sides concurrently, using measures to extend human tolerance and human capacity as far as possible on the one hand and, on the other, to mitigate stresses by providing optimal environmental support and facilitation. Such measures would include selection of astronauts with emphasis on their tolerance to stress; conditioning and adaptation programs; training—and overtraining—under realistic conditions; nutrition; possible use of supportive drugs; protective equipment, environmental engineering, and task systems engineering; psychophysiological monitoring; and organization management.

SUBJECTIVE STATES

Subjective states—emotion, dreams, imagery, fantasy, hallucinations—are of interest in long-duration spaceflight primarily from the standpoint of possible interference with high-level performance. Spaceflights thus far have not been long enough or sufficiently possessed of unoccupied time to provide the necessary conditions for shifting the predominant orientation of astronauts from objectivity to subjectivity. The prolonged cruise phase of a long-duration mission might provide such conditions. The relative social isolation, confinement, empty time, boredom, progressive reduction by habituation of objective anchoring points in the environment, changing physical state, distortion of the usual balances among sensory inputs, increased preoccupation with home and loved ones, and underlying apprehensions—these could set the stage for turning an outward orientation to an inner, subjective one. Although the probability of such a circumstance does not appear great, it merits consideration because it would likely affect the astronaut's motivation, decision-making, and collaboration with other crew members.

Man's stability and equanimity in a social world and his ability to manage his affairs depend heavily upon his maintaining an objective orientation with respect to his experiences. All experience occurs in the perceiver and is constructed by or occurs in the same perceptual-cognitive neural mechanisms of the brain; the distinction between subjective and objective experiences is whether they depend more on internal or external stimuli. The individual learns to distinguish, and to resolve conflicts, between them. Clarity and consistency in recognizing external stimuli and in utilizing skills adapted to the requirements of performances in the external world tend to keep a person oriented and attuned outward. Ambiguous, unpatterned, and unclear stimuli encourage subjective experience and allow internal factors to dominate. The latter conditions are favored by sleep and sensory deprivation.

Many cues and attributional processes are available to help the individual distinguish between the two states, and coping mechanisms draw on both subjective and objective experience to plan strategies for dealing with reality. The efficient functioning of behavior appears to depend on the appropriate sequencing of coping plans with respect to internal and external demands. Given appropriate awareness of the these factors and of the role of subjective experience, it is rather unlikely that the select crews of long-duration missions will be unduly affected by this problem.

GROUP PROCESSES AND INTERPERSONAL INTERACTION

The biological and health needs of man, both individually and collectively, have been given extensive consideration in spaceflight planning. In sharp contrast, there has been little awareness of, and attention to, his social needs, either as an individual or as a component of a small, fixed group in social isolation and confinement. Man normally is a highly social being, and his self-awareness and self-esteem derive largely from his interactions with others. Members of a social group serve as mirrors for one another, and interdependence grows up among them. In contrast, however, to the expanding social interactions characteristic of the socially open system of the everyday world, life in a spacecraft constitutes a closed system. It is a microsociety in a miniworld.

It is not clear whether, and how, such an isolated, miniworld group will stabilize its social relations and reach a steady state consistent with effective accomplishment of the mission. If social interactions are highly variable and unpredictable, group cohesion and morale may be low and accomplishment poor and erratic. If the level of stabilization of socialization is too low, interaction among members of the group may decrease to the absolute minimum required by necessity or may even go further to disrupt or jeopardize operations. Long before these levels are reached, however, serious consequences may arise through the progressive or intermittent withdrawal of one member from the group.

There are wide variations in personal social needs and in ways of adjusting to them. Similar differences and problems exist at the interpersonal level. Three important interpersonal needs are particularly relevant: the need for affiliation, the need for dominance, and the need for achievement. Within a group, need relationships may be congruent or incongruent, compatible or incompatible, complementary or conflicting, reinforcing or competitive to the point of disruption. Under conditions of isolation and confinement, conflicting and incompatible needs can lead to withdrawal and territorial reactions. If space limitations prohibit physical withdrawal, anxiety reactions, emotional outbursts, or psychosomatic stress reactions can result. Sulking, encapsulation, even paranoid reactions could develop. In all these instances crew performance would be apt to suffer, and personal and interpersonal relations could deteriorate to the point of no return. Motivation, superordinate goals, and overriding tasks will do much to forestall such possibilities on a long-duration mission. But crew selection that takes account of personality factors and individual needs, as well as compatibility and crew insight into this question, is clearly of major importance.

A SOCIAL-SYSTEM APPROACH TO LONG-DURATION MISSIONS

The microsociety of the spacecraft, which includes the craft itself, its crew, the environments in which it travels, its relations to the organization and society on which it depends, and all other factors that bear on the mission, may be viewed as a social system. Such a view facilitates a common frame of reference for organizing and planning the long-duration mission. Its underlying principle—the principle of system congruence—requires that the system be internally consistent and that all parts be compatible and mutually reinforcing.

This social system can be thought of as involving eight elements: mission objectives and goals, philosophy and value systems, personnel composition, organization, technology, physical environment, cultural-social environment, and temporal characteristics. (1) Well-defined intermediate and long-range goals, together with criteria of success, are likely to be crucial. Increased remoteness of goals and less certainty of success raise questions concerning management of the long-range motivations of crew members and maintenance of the needed support of government and the public. (2) Every group or organization is guided by some over-all system of values and ethics which is usually reflected in attitudes of the organization's top hierarchy. In the case of NASA, the value system is largely determined by national policy. The military aviation tradition of the astronaut corps is likely to be broadened in the future, but some conflict with the value systems of scientist-astronauts is a possibility. (3) Optimal personnel selection tends to be guided by compatibility with goals, values, technology, and other system characteristics. Crews of long-duration missions will probably have to be more heterogeneous than heretofore and will require persons who are patient and tolerant of inactivity. Determination of optimal composition and selection of the crew will be formidable tasks, requiring substantial new research. (4) Organizational arrangements in the spacecraft, including crew size, structure, and dynamic organization, have direct bearing on performance and the viability of the microsociety. They must be compatible with, and integrated with, mission tasks, vehicular design, and environmental constraints. (5) Life aboard the long-duration mission will be very different from the "primitive" conditions of the 1960's, and these missions will evidence many technological changes and advances in power sources, life-support systems, habitability, and communications. These must be anticipated in planning and assimilated into all facets of the mission. The new technology will have important implications, moreover, for crew selection, training, preconditioning, operational and scientific functions, and social organization. (6) The physical environment of the mission is actually twofold: the hostile outside environment and the protective environment of the spacecraft. With time, the latter environment may also be a source of stress because of enforced confinement, but the fact that the confinement is voluntary should substantially increase tolerance. Nevertheless, habitability of the spacecraft assumes major importance. (7) The cultural-social environment comprises very many complex elements, and it influences organizations and their systems. New generations of astronauts will likely be witness to cultural changes; and some differences may be anticipated in, for example, value systems, nutrition, height and weight, and education. (8) An important aspect of every social system is its temporal character. A long-duration mission involves three major temporal factors: the period of continuous isolation and confinement of the mission; the total time involved, including preparation and postmission work—possibly 5 to 15 years; and the daily cycle, which must be filled meaningfully. The total mission time involves a very substantial commitment. The critical importance of duration of a mission may be compounded by the effects of close confinement and other stresses on astronauts reared in twentieth-century American culture.

HUMAN FACTORS AND OPERATIONAL REQUIREMENTS

Missions of long duration are less likely to present completely new and unique problems in human factors and operational requirements than they are to increase enormously the complexity of these factors. These quantitative rather than qualitative differences could, especially in the time involved, prove to be serious obstacles in the absence of adequate research and planning.

Four elements of the long-duration mission are the ground-support system, including mission control; the spacecraft; the ground crew; and the flight crew. The characteristics of each will undoubtedly be modified. Ground support will likely expand greatly; it will perform command functions and provide resources for diagnosis of malfunctions, new flight plans, and scientific and medical backup. It will be crucial to crew morale and motivation through the manner in which it handles communications with the spacecraft. Mission success will depend heavily on the trust and confidence that the flight crew places in the ground crew; they should begin to work together well in advance of the mission, and both should undergo the same kinds of evaluation. Flight crew tasks will also increase, both during the mission and preflight and postflight. The length of the mission will necessitate greater crew responsibility for maintenance and repair of equipment and development of contingency plans. Time will permit more scientific work, and it is likely that the scientist-astronaut will play a larger role in the preflight development of experiments. The habitability of the spacecraft will assume far greater importance; past problems, tolerable over the short run, must be eased. Major issues at present include waste management, palatability and potability of food and water, obstacles to sleep, human engineering, and cabin volume. Volume per man and its configuration are particularly troublesome problems for the long-duration mission.

Astonishingly little is known in any precise way about optimal schedules or requirements for work, sleep, and recreation under conditions applicable to the long-duration mission. Similarly, a number of major facets of retention of critical skills and maintenance of performance have not been investigated, and it is not clear what effects the environmental stresses will have. Finally, no objective tests are available to quantify the precision with which higher-level tasks are performed. These human factors are basic to man's participation in long-duration spaceflight.

MAJOR RECOMMENDATIONS

The following recommendations, culled from the subsequent chapters of this report, represent the Study's view of the most important unresolved questions bearing on human factors in long-duration space missions. The order in which they are given roughly corresponds to their estimated impact on decisions to undertake missions of long duration.

1. Ground-based research and subsequent inflight research with man and animals should be pursued diligently over the full range of physiologically deconditioning factors. An understanding of the course of deconditioning over two years, its mechanisms, and consequences, together with validation of effective countermeasures as necessary, must be in hand before man is permitted to engage in long-duration space missions. Inflight research is visualized to include only definitive experiments that cannot be performed on the ground; cautious and conservative use of the incremental approach with man; possible use of human surrogates, especially primates, which will remain in space for long-duration studies in man-tended orbital stations; and, perhaps, unmanned animal flights to investigate discrete problems.
2. A long-duration, ground-based investigation of the immediate and cumulative effects of high-*Z* particles should be undertaken as soon as suitable facilities are available, provided that studies in the interim support present hypotheses on the nature and severity of this hazard. At the present time it appears that, like deconditioning, a thorough understanding of effects of high-*Z* particles and availability of proper protection must precede any participation of man in prolonged flights beyond the magnetosphere.
3. The long-term effects on man of isolation, confinement, and

sensory restriction, in conjunction with other stresses, are too poorly understood to permit more than rough qualitative predictions about man's capabilities during long-duration manned spaceflight. Research is critically needed to enable optimal planning and conduct of such missions. This research should emphasize, but not be limited to, the following factors, which are given roughly in order of priority (interactions have been momentarily ignored): cognitive functioning, including electroencephalogram changes; maintenance of performance and retention of skills; sleep and work–rest cycles; group processes; allocations of tasks; and perceptual and motor skills.

Many methodological issues are involved in such research, including the nature of the measures to be collected; the relative emphases to be placed on laboratory simulation, field, and model-building efforts; and the priorities to be given to individual research questions. A few comments, constituting general recommendations for a research program, are in order.

(a) No single methodological approach is adequate. Observations and measurements in a substantial number of shorter operational missions must, obviously, be systematically collected and analyzed for their relevance to longer-term missions. Training exercises in simulators should also be utilized as sources of data bearing on crew performance over longer periods of time. Long-term simulator studies such as the McDonnell Douglas series of life-support tests could be modified to increase the data bearing on human factors. Other field studies such as the Sealab and Tektite projects are useful sources of data, as these earth-bound missions are in some respects very similar to spaceflight. Laboratory studies also seem essential to clarify relationships among variables thought to be important aspects of space missions, because laboratory studies generally permit greater control over experimental variables and greater observational access than either field or simulator situations. Finally, computer and mathematical modeling efforts seem warranted and necessary, in order to synthesize the various bits of information obtained through empirical research. These methodologies, it may be noted, lie along a continuum of increasing distance from the real-world phenomena of interest, of increasing abstractness of conceptualization, of increasing "power" in the sense of reliability and replicability of results, but also of increasing difficulty in generalizing back to the real-world complexities. A valuable long-range research strategy involves efforts along all points on the methodological scale.

(b) Any program of research in such complex areas must be attentive to a variety of forms and systems of measurement. For example, four system levels important to research on microsocieties would be physiological, psychological, task performance, and interpersonal. On each of these levels measurements may take four forms: subjective reports, observations, trace measures (evidences left by an event or activity that permit reliable inferences about its occurrence), and archival measures (records and data collected and retained for other than research purposes but that provide useful research data). A solid research program would ideally attend to all levels of function and would use multiple forms of measurement to obtain greater confidence that the phenomena of interest are in fact under experimental control and observation.

(c) There are many substantive research questions demanding attention. A few of the more important are the sources of the central-nervous-system changes noted in prolonged periods of comparative monotony, the effect of training and conditioning on long-term physical adaptation and maintenance of performance, the role of interpersonal compatibility in mitigating social withdrawal and encapsulation, the role of leadership in maintaining adjustive interpersonal relationships, and the effect of expectations or "set" on experimental results.

4. Implicit in the above recommendations is the belief that techniques must be available to measure, at appropriate intervals, the crew members' physiological, psychological, and performance status inflight. Inflight measurements and tests of these parameters are critically important for providing early indications of potentially serious situations and, hence, helping to avoid or minimize them. Objective methods to measure precisely higher-level performance are very much needed as are tests for incipient psychological or psychiatric problems. Inflight techniques should emphasize principles of noninterference, automation, and monitoring for critical deviations in biological parameters that best predict reductions in well-being. Substantial research and development will be necessary to attain these goals.

5. If man is to participate in long-duration spaceflight, his requirements—physical, psychological, behavioral, and interpersonal—must be given far more attention than has heretofore been the case in the design of the spacecraft and the mission. Requirements for life support and safety, optimal habitability and comfort, and operational efficiency should be incorporated into spacecraft engineering from the beginning. Habitability in particular must be improved, especially with regard to capsule volume, configuration, and noise as these re-

late to work, mobility, exercise, recreation, and sleep. Broad research programs, with close coordination among aerospace engineers, life scientists, and human-factors experts, will be necessary to identify and accommodate the many elements involved.

6. All the elements of the long-duration mission should be viewed as portions of a totally integrated and mutually reinforcing system. These elements include temporal factors–preflight and postflight as well as inflight; engineering factors–spacecraft and its internal environment–and new technology; operational factors–ground support, mission control, and space mission; scientific factors–inflight experiments, their preparation and completion, medical care, and ground-based resources; and human factors–ground crew and flight crew and their relations. Owing to the complexity of the system, which will be increased by its dynamic nature, the systems-analysis approach should be advantageous in providing a common frame of reference for interdisciplinary planning and implementation.

7. Crew composition and criteria for its selection should be considered matters of first importance, representing one culmination of the research called for in Recommendation 3.

2 Physiological and Medical Factors

The purpose of this chapter is to provide an overview of physiological and medical factors believed to be relevant to long-duration missions and a framework for discussions in succeeding chapters about the behavioral, social, and human-factors aspects of such missions. The possible effects of spaceflight on man's physiology and health have received concentrated and continuing attention since well before the first manned flights were made and have been the topic of much theorizing and speculation. The discussion that follows attempts to summarize the more important findings and hypotheses, with references to in-depth studies reported in the literature. Because of the extensive research being carried on in these fields and the experience being accumulated from each successive manned mission, understanding of physiological and medical aspects of spaceflight is the most sensitive to change of any of the topics treated in this report. Unfortunately, the results of the Soyuz 9 and 11 flights and the Apollo 15 mission, which may be the most informative of any to date, are not yet available in the literature as this report goes to press.

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PHYSIOLOGICAL FACTORS

The physiology of long-duration manned spaceflight can be regarded as the physiology of a restrictive environment that contains some unique additional phenomena. The major features of the spacecraft environment are those of weightlessness and confinement, the effects of which might well be re-enforced by prolonged exposure to the unchanging sameness of a carefully regulated space-cabin environment. Further effects might be observed in the absence, or reduced influence, of normal terrestrial *zeitgebers* (time references) and in exposure to increased ionizing radiation and perhaps altered magnetic fields. The accelerations and decelerations of launch and re-entry are not features of prolonged space missions *per se*, and the significant but generalized physiological responses to fear, pleasure, and changing interpersonal relationships belong more in the realm of psychology and sociology.

Experience in actual spaceflight has, of course, been extremely limited and of relatively short duration. The most stressful U.S. flight in terms of both confinement and weightlessness was probably the Gemini 7 mission in which two astronauts completed a 14-day mission in a vehicle allowing about 40 ft^3 per man of free volume. Apollo flights, although approximately as long, allowed considerably more free volume per man, free movement in the capsule and lunar module, and considerable overlapping use of space. Significant physiological changes were observed as a result of the Gemini missions, including decreased tolerance to tilt-table stress postflight, loss of work tolerance, loss of red-blood-cell mass, electrolyte changes, increase in white blood cells, and some loss of calcium (Berry *et al.*, 1966). Even in the Apollo programs, however, significant findings were observed, e.g., loss in bone density and muscle mass, cardiovascular deconditioning, loss in exercise capacity (Kerwin, 1969).

Studies attempting to simulate the effects of weightlessness have of necessity included some form of inactivity and confinement as a major element in the simulation (Lamb *et al.*, 1964a) and in some cases have investigated the effects of altered atmospheres. Until the effects of inactivity and weightlessness have been separately evaluated, the contribution of each to the total cannot be properly assessed. It seems probable that in some respects weightlessness acts to relieve some of the stress of restrictive confinement, e.g., seat pressure, while aggravating other aspects, e.g., cardiovascular deconditioning and loss of skeletal calcium. The physiological effects of various forms of restrictive environment are well documented, mostly with reference to exposures lasting from a few days to a few weeks. Notable among these have been reports relating to the effects of immobilization by way of a plaster cast (Dietrick *et al.*, 1948), studies of bedrest (Birkhead *et al.*, 1963; Miller *et al.*, 1964a, 1964b), the effects of confinement in special rooms (Alluisi *et al.*, 1963; Hanna *et al.*, 1963; Lebedinsky *et al.*, 1964). Perhaps more closely related to space missions have been studies of submarine confinement (Fawcett and Newman, 1953; Weybrew, 1963) and in space-cabin simulators (Celentano *et al.*, 1963; Lawton *et al.*, 1964; Grodsky and Bryant, 1962; Hanna, 1962; Lamb *et al.*, 1964a). More recently, some longer space-cabin simulations have been conducted, including the 56-day exposure to an oxygen–helium environment in the USAF School of Aerospace Medicine environmental simulator (Hargreaves *et al.*, 1966), and the 60- and 90-day closed-loop system manned simulations conducted by the McDonnell Douglas Astronautics Company (Taliaferro and Seaman, 1969; McDonnell Douglas, 1971). Very-long-duration exposure, however, has been left so far to Soviet investigators, who report on exposures of selected scientists to as much as a year in chambers with closed or partially closed ecological systems (Burnazyan *et al.*, 1969; Kosmolinsky and Dushkov, 1968; Zhurgvlev *et al.*, 1967; Gorbov *et al.*, 1964; Lebedinsky *et al.*, 1964).

In addition, various comprehensive reviews are available, including in particular those of Roth (1968) on weightlessness, Fraser (1966, 1968a) on confinement, and the reports of the Space Science Board (1967, 1968b). Disregarding for the moment the stressful phenomena of launch, intercurrent emergency, emotional reactions, and landing, the physiological effects of the space environment are manifest in the form of a physiological deactivation together with adaptive responses to weightlessness and restriction. Most apparent is the physical deconditioning observed in the cardiovascular and musculoskeletal systems.

CARDIOVASCULAR SYSTEM

Cardiovascular deconditioning is a concomitant of prolonged exposure to a restrictive environment and may be expected in a long-duration space mission. Its genesis, pathophysiology, and prognosis remain conjectural in important aspects (McCally, 1968). The phenomenon can be attributed in part to the fact that on earth, under the influence of gravity, the hydrostatic pressure head is proportional to the length of the column of liquid. Consequently, in the supine position, the pressure differential between head and feet is negligible, and a reduced requirement exists for the cardiovascular system to combat the pressure head. In 0 *g* there are no gravitational hydrostatic gradients; the only vascular pressures are those produced by body tissues, e.g., myocardial and skeletal muscle and elastic tissue, neither of which is affected by weightlessness. Since deconditioning also occurs in the seated position and in confined situations where some free movement is possible (Lamb *et al.*, 1964a, 1964b), it would seem that other factors are involved in the loss of conditioning besides a drop in the pressure head. The factors involved no doubt include disuse atrophy of muscle, diminished action of the muscle pump, and loss of blood volume mediated through fluid volume receptors.

The effects of weightlessness on the control and regulation of cardiac and vascular function in particular have not been clearly established, although some of the end results are apparent as physical deconditioning. It is probable that significant changes take place in the pattern of response of the mechanoreceptors in the walls of the blood vessels and in the cardiopulmonary reflexes, which in turn affect the tone of the system and the output of the heart rate, as well as the regulation of the fluid volume. Furthermore, as a capacitance system, the veins are reduced in effectiveness in the absence of a gravity field. The long-term effects of these changes have not been evaluated, and no actual measurements have been conducted on man during prolonged exposure to weightlessness. Data from the Biosatellite 3 primate flight (Adey *et al.*, 1969; Biosatellite III Results, 1971; Meehan and Rader, 1971) indicate central pooling of blood with resultant increase in central venous pressure, diuresis, and loss of fluid from the body, but whether these results can be ascribed in total or in part to weightlessness is under debate (*cf.* House Committee on Science and Astronautics, 1970).

The cardiovascular deconditioning occurring under conditions of close confinement has been demonstrated most clearly by orthostatic intolerance, as illustrated by tilt-table studies, and by decreased tolerance to exercise (Lamb *et al.*, 1964a, 1964b; Miller *et al.*, 1964a, 1964b). Russian workers (Lebedinsky *et al.*, 1964) showed a decrease of about 20 percent in cardiac stroke volume and minute volume of their subjects after 10 to 15 days of confinement and stated further that these measurements failed to reach preconfinement level on exercise loading. It would seem that in confined conditions at 1 *g* the occurrence of cardiovascular deconditioning is related to the available free volume, to the presence or absence of exercise, to the level of habitability, and to the duration of confinement (Fraser, 1968a). Thus, in the School of Aerospace Medicine space-cabin experiments discussed by Lamb *et al.* (1964a), where the full volume in the one-man cabin was approximately 50 ft^3, postconfinement deconditioning was manifest by decreases in exercise tolerance and endurance, decrease in orthostatic tolerance to tilt-table exposure, and decrease in blood volume and hemoglobin. Similarly, in the studies of Celentano *et al.* (1963), where the smallest cabin allowed about 55 ft^3 per man, subjects experienced a rise in blood pressure and heart rate subsequent to leaving the cabin, with complaints of dizziness, weakness, and fatigue on walking. Comparable effects, apparently lasting two weeks postflight, are suggested by Soviet press reports on the 18-day Soyuz 9 mission in mid-1970; it may be noted that the Soyuz spacecraft is more cramped than the Apollo command module. In the manned lunar mission simulation of Grodsky and Bryant (1962), where a strenuous exercise program was part of the protocol and each man had about 135 ft^3 of free space, no deterioration was observed in postconfinement performance of athletic endurance tests and the Harvard step test. Similar results were obtained in longer-duration studies (Lawton *et al.*, 1964; Zeft *et al.*, 1966; Taliaferro and Seaman, 1969), where exercise programs, free space, and high levels of habitability were a feature. However, in bedrest studies simulating weightlessness, daily supine bicycle exercise for 2–4 h was not effective in preserving orthostatic tolerance (Birkhead *et al.*, 1966). It remains to be determined whether active exercise programs and satisfactory habitability and free volume will have any significant effect on cardiovascular deconditioning in prolonged weightlessness.

MUSCULOSKELETAL SYSTEM

Musculoskeletal deconditioning is also found during and after exposure to a restrictive environment. Muscle atrophy is indicated by flaccidity and loss of substance, particularly in those muscles normally active in weight-bearing. Although found particularly in weightlessness and on exposure to close confinement in conditions of reduced weight-bearing, especially during bedrest, some loss of muscle substance appears to occur in less-confined situations. Evidence of protein breakdown in spacecraft (Kerwin, 1969) and spacecraft simulators (Lawton *et al.*, 1964) is suggested by a trend toward negative nitrogen balance from loss of muscle nitrogen.

Decalcification of bones is a characteristic finding of skeletal atrophy and has been shown to occur in spaceflight (Berry *et al.*, 1966; Parin, 1968; Kerwin, 1969; Biosatellite III Results, 1971). Hattner and McMillan (1968), in a review of the influence of weightlessness on the skeleton, predict that calcium loss will be in the range of 1–2 percent per month, probably unremitting for a year to several years during exposure. They conclude that although specific vascular and neuronal influences cannot be excluded as a causative factor of disuse osteoporosis, the more important determinant appears to be the absence of mechanical strain and compression of bone by the interaction of muscle and gravity. Bone formation may decrease early in immobilization; it then increases above the preimmobilization rate for a time and finally recedes to normal or below. Since atrophy is progressive during this time, resorption must always be exceeding formation. In man the first phase has not been seen regularly, but when it occurs it appears to last up to six months, the second phase another six months. Calcium balance studies in normal immobilized humans have not been carried out for durations of longer than two months, and consequently the time to steady state is not yet known. In paralyzed subjects it seems to occur in about two years. The danger of pathological fracture, however, has probably been overestimated. As Hattner and McMillan point out, these fractures have only been reported in association with radiographic thinning, which requires at least 30 percent skeletal loss. At a loss rate of 1–2 percent per month, a loss of this magnitude would require 22–51 months of exposure in an immobilized state or its equivalent. Another, and perhaps more possible danger, arises from free-circulating calcium. Free-circulating calcium in excess of normal requirements encourages the undesirable calcification of tissues and the formation of kidney and other stones. Stone formation, of course, will not occur merely because of excess excretion via the kidney. Numerous other factors are involved. But the inherent danger does exist, and in a voyage of a year or so presents a serious, if unlikely, hazard (Busby, 1967b).

Means to reduce decalcification are discussed in detail by Hattner and McMillan (1968) and Busby (1967b). Three modalities show possibility, namely, diet, pharmacological therapy, and physical therapy. Probably the most useful preventive measure lies in weight-bearing or in exercises designed to simulate weight-bearing. The crew of Gemini 7, who practiced isometric exercises in space, showed less reduction in the radiodensity of bone than did the Gemini 5 crew who performed no exercise. Isometric exercise will also prevent normal muscles from atrophy during immobilization. It would, therefore, seem likely that even in long-duration missions, provided that free space and habitability are adequate, the normal motions of movement in the cabin combined with a suitable regimen of exercise should be sufficient to minimize the potential hazards of musculoskeletal deconditioning.

FLUID VOLUME AND ELECTROLYTIC AND WATER BALANCE

Various studies on subjects in restrictive environments and in bedrest have shown an increase in urinary sodium excretion that is maintained throughout the experiment (Space Science Board, 1968b). These subjects also experience a profound water diuresis evident within 8–10 days. At least two controlling mechanisms are involved in bringing about the changes—one related to alteration in the hydrostatic pressure load applied to the fluid volume receptors and the other to generally diminished sympathetic activity. In the confined or bedrest state, the factor influencing the hydrostatic change is alteration of the height of the pressure head (h in the product ρgh), whereas in weightlessness the significant change occurs in the g term. In the weightless state, the intratissue pressure is much less affected by hydrostatic gradients than is the vascular pressure. Hence the balance of pressure favors the absorption of tissue fluid and an initially increased blood volume. This in turn stimulates stretch receptors in the atria and, by way of the Gauer-Henry reflex, initiates impulses that travel to the hypothalamus-hypophysis and inhibit the release of antidiuretic hormone (ADH). Reduction in ADH acts on the kidney to cause diuresis and restore normal blood volume. Simulation and spaceflight studies suggest that a new equilibirum is reached fairly rapidly, with final maintenance of blood volume below the normal found in the active subject at 1 g. Even in space-cabin simulation where no attempt is made to simulate weightlessness, some decrease in plasma volume and total body water is observed (Morgan *et al.*, 1961; Rathert *et al.*, 1964; Lawton *et al.*, 1964; Celentano *et al.*, 1963), although in some of the latter studies the situation is confused by the possibility of increased evaporative fluid loss because of reduced air density.

In both confinement and weightlessness there is probably also a decrease in general sympathetic tone and in particular decreased renal sympathetic activity. In the closely confined situation this diminished reaction occurs because of the enforced inactivity, whereas in weightlessness any postural adjustments that are made do not result in gravity-dependent stimulation. The decreased renal sympathetic activity tends to increase urine flow rate and sodium excretion, as has been observed in astronauts during spaceflight. Loss of sodium in turn activates the renin–angiotensin–aldosterone–sodium control loop until again a new equilibrium is established at a lower value with a decrease in aldosterone secretion by the adrenal cortex and an increase in sodium loss (Space Science Board, 1968b, p. 70).

It is not possible at this time to predict the final outcome of water and electrolyte balance under conditions of prolonged spaceflight, since the studies so far conducted have been few and of relatively short duration. Although by terrestrial standards dehydration and electrolyte loss occur in astronauts in spaceflight, their actual level of hydration is attuned to the environment in which they are existing, and subjectively at least, no problem has been observed; in particular, thirst is not a feature. The Gemini 7 flight showed that when fluid intake is deliberately increased, hydration can be maintained near to terrestrial levels, but whether this is necessary or even desirable is not clear at this time.

HEMATOLOGICAL FACTORS

Decreased hematocrit, decreased hemoglobin, and decreased red-blood-cell (RBC) mass have been observed irregularly in several confinement studies (Celentano *et al.*, 1963; Lamb *et al.*, 1964a) but by no means in all. In the Gemini program, and in simulators with a 5-psi, 100% O_2 atmosphere, loss of RBC mass is even greater than would have been expected from the bedrest studies (Berry *et al.*, 1966; Roth, 1967a).

Evidence suggests two hypotheses to account for the loss in RBC mass after exposure to hyperoxic atmospheres: a physiological decrease in red-cell mass from diminished requirement for red cells in the face of increased pO_2 and a pathological destruction of red cells by oxidative injury to the red-cell membrane, perhaps by the creation of lipid peroxides or oxidation of other structural membrane components (Roth, 1964). In the Apollo series, loss of RBC mass has been noted only in those flights with extravehicular activity, that is, in flights where the atmosphere has been purged, during decompression, of residual nitrogen left over from the mixed O_2–N_2 atmosphere at launch and replaced with 100% O_2. In confinement under conditions of 1 *g* and an air atmosphere, any RBC loss is irregular in occurrence and is observed only when subjects have been highly active immediately before confinement. This may, in fact, be a manifestation of the normal physiological increase in destruction of red cells that occurs with exercise and is apparent in subsequent rest.

It would seem, therefore, that changes in RBC mass are primarily due to the hyperoxic atmosphere and not to weightlessness or other elements of the spacecraft environment. Should the atmosphere used in prolonged missions be akin to air, significant changes in RBC mass will probably not occur. In missions in the range of 1000 days, the formation of biliary pigment calculi is conceivable, but if RBC destruction is sufficiently moderate that the load of bile pigments is no more than doubled, then the chance of calculi formation is slight (Space Science Board, 1968b, p. 123).

The possibility of hemolytic anemia during extended excursions into space merits some special consideration. Red blood cells normally survive about four months. Experiments in abnormal atmospheres have not as yet extended into that length of time, and, consequently, it is not yet known what might happen to RBC structure and function under prolonged atmospheric stress. With a normally functioning marrow, the observed loss of RBC mass in Gemini astronauts should have been repaired very promptly. Yet at 18 days postflight the reticulocyte count was still elevated, which would seem to indicate some delay in the reparative process or a persistence of hemolytic disease or a continuing loss of blood. No follow-up, however, was undertaken, and the situation remains in doubt.

Several other actual or potential hematologic problems have also been considered (Crosby, personal communication), including the effect of high-*Z* particles on the marrow. The marrow is highly sensitive to the effects of ionizing radiation. It is known that high-*Z* particles will cause chromosome damage in this rapidly proliferating tissue; it is not known, however, to what extent bombardment of this type will occur or will increase the attack rate of neoplastic disease. Other unknowns in the field of hematology concern the effect of the restrictive or abnormal atmospheric environment on RBC enzyme systems. Dysfunction of some enzyme systems leads to hemolytic anemia. Other enzyme systems, however, can be deficient without evident effect on the erythrocyte under normal terrestrial conditions. It is not known how these deficient cells might function or survive in abnormal atmospheres over extended periods of time. Still another unknown hematologic field concerns the function of the hemostatic system in the weightless state and in abnormal atmospheres. Attention will have to be directed to the morphology and behavior of platelets, including the possible effect of abnormal atmospheres on the platelet turnover in the lung, as well as the presence and continued normal function of other elements in the hemostatic system.

RESPIRATORY SYSTEM

On the basis of information available to date, the effects of the environment of space, including the effects of weightlessness, on the respiratory system appear to have been minimal. Ground-based work suggests that confinement *per se* has little effect other than a trend for respiratory rate to drop somewhat after the first few days (Hanna, 1962; Alluisi *et al.*, 1963; Lebedinsky *et al.*, 1964). The possible effects of long-duration missions on the respiratory system were considered in detail by a Space Science Board (1967) study. The consensus favors the belief that significant changes may occur, but that they will not be overly deleterious.

NUTRITION AND METABOLISM

The effects of inadequate nutrition tend to be long-term and cumulative rather than immediate. Thus the duration of space missions to date has probably not been sufficient to demonstrate any effects that could be attributable to deficient nutrition.

As has already been noted, a strong trend toward decrease in body weight has been observed in most studies involving restrictive environments, although not in all subjects in those studies. How much of this weight loss is due to loss of fluid, how much to muscle atrophy, and how much to reduced intake cannot be determined. Weight loss, however, has occurred despite the availability of an adequate diet (Lamb *et al.*, 1964a), and food intake has been considerably less than the calculated ideal (Lawton *et al.*, 1964; Vanderveen *et al.*, 1966). Widely differing caloric intakes ranging from 1500 to 2500 kcal, have been reported in apparently similar Gemini missions. Interpretation of these findings is complicated by food acceptability (no less among astronauts than among subjects in simulators), individual differences, and the severity of restriction of movement in spacecraft; but studies involving analysis of dietetic demand in subjects confined in simulators have shown intakes ranging from 1700 to 2550 kcal per day (Rathert *et al.*, 1964; Lawton *et al.*, 1964; Grodsky and Bryant, 1962), a range that is not incompatible with the 2000 kcal per day normally considered to be the requirement at bedrest in a thermoneutral environment. Since the higher level of the range was found in conditions where more free movement was available, the findings would suggest that the severity of the restrictive environment is a major factor both in limiting energy output and in depressing the appetite.

Adequate nutrition, however, involves more than provision of food energy and entails consideration of supply and proper balance of all food requirements. At the Conference on Nutrition and Related Problems (NASA/NAS, 1964) it was noted that the advent of partially or completely synthetic diets, likely to be used in prolonged spaceflight, may, with their limited variety and their mineral components, introduce problems heretofore unknown. Individual variations in nutritional requirements may also assume importance in prolonged spaceflight. Requirements for essential amino acids vary by as much as a factor of 2, and vitamin requirements by a factor of 3. Thus items supplied in amounts suitable for some individuals would be excessive for others. Weightlessness *per se*, however, would appear to have little or no effect on nutrition; and despite justifiable warnings about synthetic diets, the Russians have clearly shown that subjects, while perhaps showing other changes, can thrive for as long as a year in a sealed chamber on a largely synthetic diet. In the work reported by Burnazyan *et al.* (1969), where the diet consisted of vacuum-dried foodstuffs, including dehydrated milk and meat supplemented by green plants grown in the chamber, one subject after initial loss of 2 kg finished the experiment with a gain of 1.5 kg; a second subject gained 1 kg, while the third lost 3.5 kg, but all remained in a state of good nutrition. Thus it would appear that nutritional requirements can be adequately met and should present no insoluble problem.

Heat production and thermal regulation, however, require study from two viewpoints. First, little is known about efficiency of muscular work in weightlessness. There are indications from extravehicular activity in Gemini 11 and 12 flights that this may be reduced (Berry, 1968). Second, thermoregulation in the mammal may be adversely affected in weightlessness, due, for example, to altered blood flow in brown fat tissue (Masoro, 1966). The extent to which related but different mechanisms in man are involved is not yet known.

ENDOCRINE SYSTEM

Here, available data are minimal. An apparent suppression of steroid and other hormone excretion has been reported in the later phases of some missions (Lutwak *et al.*, 1969), but no conclusions can yet be drawn on any aspect of this important factor in man's well-being.

Other endocrine functions are even less well understood. In prolonged missions, degradation of endocrine functions may be slow and subtle, and thus there is need for a continuous monitoring capability inflight. This does not now exist.

CENTRAL NERVOUS SYSTEM

The role of circadian rhythms in influencing the periodic cyclic changes of physiological function has become clearly established (Aschoff, 1965a), although the influence of disturbance of circadian rhythms on the response to stress within the environment and on performance is less well established. Circadian periodicity is predominantly, perhaps entirely, endogenous in origin, as is illustrated by the fact that when the normal *zeitgebers* or time references, such as light and dark and environmental temperature, are held constant the rhythms persist, although they may tend to become free-running with slightly different periods which may be longer or shorter than the normal 24-h day. Restoration of *zeitgebers* to normal periodicity entrains the free rhythms to the diurnal cycle. *Zeitgebers* can be reinforced by establishing fixed work–rest cycles, the more so if the latter are programmed to the light–dark cycle. In the absence of natural *zeitgebers* the periodicity can be maintained by programming artificial cycles in submultiples of the 24-h day, although some latitude can be tolerated in either direction. If the difference is more than an hour or two, however, free-running rhythms escape from entrainment, as illustrated in the work of Simpson and Lobban (1967) with an artificial 21-h day.

In prolonged spaceflight, where the space-cabin environment is rigorously controlled, there are, of course, no natural *zeitgebers*. Reliance will have to be placed on the requirements of work–rest cycles and artificial light control to ensure entrainment of periodic rhythms. Individual differences in periodicity exist, however, and a cycle system that might be suitable for one might not be ideal for another. Marked individual differences were observed in Gemini astronauts, with, on one mission, a marked periodicity in heart rate demonstrated in one astronaut and no periodicity in the other (Berry *et al.*, 1966).

It is possible that prolonged weightlessness may affect circadian rhythms and other biological cycles essential to man's well-being, even where adequate *zeitgebers* are imposed in the environment (Aschoff, 1965b). Sleep problems have been common and have been attributed to nonsimultaneous sleeping of crew, excitement, threat of danger, noise, and unfamiliar environments. Obviously, maintenance of circadian rhythms and their careful and continuing evaluation by records of such parameters as brain-wave activity, heart rate, respiration, and body temperature will be of great importance (Halberg *et al.*, 1965). Not only will these data be important in assessing individual well-being, but simultaneous data from different individuals should play a major role in assessing group interactions.

It would seem, however, that even in a highly controlled environment, subjects with considerable differences in individual traits and periodicity can, in fact, adapt to each other and maintain a good level of performance. In a carefully monitored study, Schaefer *et al.* (1967) isolated two subjects for nine days in a constant environment with measures of various physiological functions and psychomotor tests. The two subjects were of different body build and personality trait configurations. They reacted to the environment in a divergent manner but were able to adjust to each other's differences and showed a tendency to improvement in performance of the measured tasks. The phase of their periodicity shifted during the nine days and eight nights of isolation an average of 1.75 h per day, and the diurnal cycle increased to a period of 25.75 h. Pulse rate, body temperature, and basal skin resistance followed the phase shift, but respiratory rate became dissociated. Urine functions remained in phase for the first five days but became dissociated for the last three.

The foregoing brief discussion, which in no way attempts to summarize all the work that has been done on circadian rhythms, tends to support the view that in the absence of natural time-givers circadian periodicity can be maintained by artificial means, and further, that even if the maintenance is inadequate and free rhythms break out, the resulting physiological phase shifts are not incompatible with continued good performance. Thus, while in prolonged spaceflight it would be highly desirable to maintain a circadian periodicity by cyclic environmental control and work–rest scheduling in multiples or submultiples of 24 h, a breakdown of diurnal periodicity would not necessarily lead to an unacceptable impairment of function or decrement in performance.

Motion sickness has occurred on a number of flights despite preconditioning of astronauts through exposures to simulated and actual flight maneuvers and weightlessness and despite techniques to counteract incipient nausea. Unrestrained movement in the larger volumes of Apollo spacecraft has evidently caused the astronauts to be more prone to stomach awareness and dizziness (Berry, 1969, 1970). Vestibular involvement is clear, but most of the cases of motion sickness have occurred in association with the prodromal, acute, or recovery phases of upper respiratory or gastrointestinal infections (Hessberg, private communication). It is reasonable to expect that susceptibility to motion sickness is greater when a person is not feeling well. Results of the Orbiting Frog Otolith experiment (Space Science Board, 1971) encourage the view that the vestibular apparatus will adapt satisfactorily to 0 *g*, but the potentially critical consequences of motion sickness dictate the need for continued study of this problem.

GENERAL ADAPTATION TO PROLONGED RESTRICTIVE ENVIRONMENTS

The work in the field of very prolonged confinement has been done by the Russians, notably the studies reported by Kosmolinsky and Dushkov (1968), Lebedinsky and his colleagues (1964), and Burnazyan and co-workers (1969), who describe exposures to sealed environments lasting up to one year. Kosmolinsky and Dushkov recognize four phases in the general adaptation process. The first phase, of one or two days, is a period of excitement and physiological activation. This response was also observed by Hanna (1962), Tiller and Figur (1959), Gorbov *et al.* (1964), and Celentano *et al.* (1963). The second phase, from the second to the eighth or tenth day, is characterized by an "unstable adaptation." It is of interest to note that EEG changes during experiments of a known ten-day duration were considerably more pronounced than during the first ten days of a two-month experiment, while during the first month of a four-month experiment the EEG of the subjects was more stable than it had been in the preconfinement studies (Gorbov *et al.*, 1964).

The third phase, according to Kosmolinsky and Dushkov, is one of stable adaptation, which continues until the last few days of the experiment but is accompanied by a steady process of increasing fatigue. According to Lebedinsky *et al.* (1964), however, at about the midpoint of a four-month experiment there is a resurgence of stress symptoms with increased fatigability, change in sleep function, weakening of immunal activity, further loss in exercise tolerance, and decreased work efficiency, followed by increased apathy and disinterest. This finding, however, was not confirmed in the year-long study reported by Burnazyan *et al.* (1969), perhaps because in the latter study the subjects were scientists who continued active, meaningful work while in a confined situation in which habitability was maintained at an optimal level. The fourth phase, during the last day or two of the confinement, is one in which volitional processes assume predominant importance as has been observed in most confinement studies.

Of major significance is the fact that although obvious physiological changes were observed during the stable period, the test subjects were able to maintain good mental and physical performance throughout a year-long experiment, including reaction to provocative and emergency situations. Admittedly, the confined situation was reasonably habitable and not one of weightlessness in the confines of a spacecraft cabin, but nevertheless the findings auger well for the likelihood of successful adaptation to prolonged spaceflight if spacecraft conditions are made optimally habitable and measures are taken to minimize the effects of weightlessness.

COUNTERMEASURES TO DECONDITIONING

The deconditioning induced by restrictive environments, including that of spaceflight, gives rise to orthostatic intolerance, loss of exercise tolerance and muscle power, diuresis with reduction in fluid volume and circulating blood volume and perhaps RBC mass, loss of skeletal calcium, and reduction of norepinephrine output. It is hypothesized that these changes represent the body's adaptation to weightlessness and that they will reach a steady state at optimal functioning for that environment. If this is in fact the case, then the critical factor becomes the physiological stress imposed by a change in state, i.e., to gravitational forces, whether accelerations or entry into planetary gravity. In assessing the feasibility of long-duration spaceflight, first priority should be given to determining the validity, or limits, of the above hypothesis. This determination will indicate whether countermeasures to deconditioning will be mandatory throughout the flight or—depending on the type of countermeasure—only in preparation for or during gravitational stresses. In the interim, concentrated attention should continue to be given to the evaluation and testing of the effectiveness of such countermeasures.

Known approaches to prevention of, or reduction in, deconditioning include, either alone or in combination, provision of adequate *free space* and *habitability*, participation in active *exercise* programs, application of various forms of *positive and negative pressure*, exposure to *artificial gravity*, and the use of *drugs*.

Habitability Assuming an optimal environmental control system, one of the primary requirements of habitability is the availability of adequate free living space. Actual volume requirements per man cannot be specified with any degree of authority; analysis of requirements and experience suggests that for durations of 300–400 days, or perhaps beyond, the absolute minimal acceptable living space for operations with more than one crew member would be about 200–250 ft^3 per man; the acceptable would be about 350–400 ft^3; and the optimal, maximizing habitability in the light of other requirements would be 600–700 ft^3 per man (Fraser, 1968a). Provision of adequate free volume does not, however, automatically guarantee habitability, but appropriate configuration of the available volume can contribute much overall. Lebedinsky *et al.* (1964) note with reference to long-term exposure that if the cabin is designed to reflect normal living as closely as possible in its physical conditions and varied decor, the less pronounced will be the reactions. Where habitability is optimal and free movement with associated exercise is possible, the body is better prepared to combat the stress of deconditioning factors.

Exercise Periodic physical exercise and maintenance of an optimum level of physical fitness before and during exposure to restrictive environments has been employed with varying degrees of success. It has been suggested that exercise of the lower extremities might reduce the tendency to venous pooling by maintaining muscle tone, strength, and mass, and possibly the effectiveness of vasoconstrictor mechanisms (Beller *et al.*, 1966); but while there is little doubt that exercise, both isotonic and isometric, tends to reduce muscle atrophy and perhaps decalcification, its effect on cardiovascular deconditioning is less marked, as evidenced by bedrest studies (Birkhead *et al.*, 1966) and by the deconditioning observed following the Gemini and Apollo missions, in both of which isotonic exercises were featured (Berry *et al.*, 1966; Kerwin, 1969). Nevertheless, exercise programs are of value and should be encouraged, not only because of their effect on the musculoskeletal system but because of their effect on morale. All subjects in sealed cabins who have participated in exercise programs have commented favorably on them.

Pressure Various forms of applied pressure have been employed, both in ground-based restrictive environments and in space missions, in an attempt to combat the fluid volume loss and orthostatic intolerance of deconditioning (e.g., McCally *et al.*, 1966, 1968; Hunt, 1967). Extremity cuffs used in Gemini flights had no significant effect on the reduction of orthostatic intolerance (Deitlein and Judy, 1966). Lower-body negative pressure has also been used to simulate hydrostatic pressure, in that the application of lower-body negative pressure encourages pooling of blood caudally, thereby increasing transudation of fluid, rehydration, and restoration of tissue tension in the lower extremities. The technique appears to be effective in retaining orthostatic tolerance (e.g., Lamb and Stevens 1965; McCally *et al.,* 1966). Use of a modified *g*-suit such as those employed in military aviation might provide the support needed for re-entry or other gravitational forces.

Artificial Gravity Exposure of the spacecraft crew in long-duration missions either to periodic centrifugation or to continuously applied acceleration imposed by rotating the vehicle has been suggested as a substitute for gravitational pull in the event that this proves to be physiologically necessary and other methods are not effective. Much of the centrifuge work was done in connection with development of the Manned Orbiting Research Laboratory (MORL) vehicle (White *et al.,* 1965). Centrifugation is in the form of $+G_z$ spin around or close to the axis of the heart. The optimal *g* time profiles and the optimal gradient for minimizing deconditioning are not established, but it has been shown that four 7.5-min exposures to a level of $+4G_z$ at the foot largely prevents orthostatic intolerance as judged by syncope on tilting. The heart rate and blood pressure responses and the loss of plasma volume are improved over those of noncentrifuged controls but not to the pre-experimental level. Combination of exercise during the experimental period (immersion) and centrifugation improves the response still further (Nyberg *et al.,* 1966; White *et al.,* 1966). With loads of longer duration—$4.7G_z$ at foot level for 20 min four times per day—both the syncopal and heart rate responses to tilt are alleviated. Untoward responses have included discomfort in the legs and feet, and petechiae in the feet. Artificial gravity by rotation of the entire vehicle should have an effect at least as useful as that of centrifugation and in addition would probably give a more convenient and comfortable environment. Nevertheless, the cost of artificial gravity would be high in both monetary and engineering terms, and the physiological problems solved might be replaced by others of comparable importance, so that other countermeasures to deconditioning would normally be preferable.

Drugs Hormones and drugs have also been used, primarily in an attempt to control the fluid loss of deconditioning. Administration of antidiuretic hormone in the comparative study of McCally *et al.*

(1968) was shown to prevent the immersion diuresis but was without effect on the response to tilt. The same finding has been observed with respect to pitressin (Hunt, 1967) and to 9-alphafluorohydrocortisone (Stevens and Lynch, 1965).

SPECIAL PROBLEMS

In long-duration spaceflight the significance of the response to acceleration and deceleration is no different from that in short-duration flight except insofar as the severity of deconditioning is concerned. Consequently, the problems of acceleration have not been singled out. Similarly the likelihood of exposure to extremes of heat and cold and to toxic contamination is no different from that found in lunar flight except that the longer duration of total exposure to potentially hazardous conditions provides a greater opportunity for the occurrence of some undesirable contingency.

Consideration must be given, however, to two phenomena about which relatively little is known, namely, *high-Z particles* and increased or decreased *magnetic fields*.

The possibility that high-energy particles of high atomic number may present a very serious biological hazard in missions outside the earth's magnetosphere has come to light from the Apollo lunar flights. Astronauts have reported sighting light flashes during periods of dark in the spacecraft, in one eye at a time and even with eyes closed, in translunar portions of the missions. Ground-based experiments by Budinger *et al.* (1971), in which the investigators exposed their eyes to fast neutrons, induced visual sensations approximating those reported by the astronauts. These data, and the cosmic-ray tracks in the Apollo helmet dosimetry experiments (Comstock *et al.*, 1971), suggest that the sensations are caused by high-Z particles ($Z \geqslant 8$) passing through the retina and stimulating the optic nerve directly or causing a shock wave in the vitreous humor that triggers a light flash. Such particles, depending on their numbers and their occurrence in various regions of space, could represent a serious problem on long-duration planetary flights, particularly with respect to destruction or damage of nondividing cells of the nervous system and other controlling cells. Research to determine the correctness of this model and assess the severity of the problem, and incorporation into the spacecraft of adequate shielding—if that should prove necessary—without prohibitive increases in weight, could be pacing items for interplanetary missions.

With regard to magnetic fields, the astronaut in interplanetary space will normally be exposed to a field of about 10^{-4} to 10^{-5} G, considerably less than that of earth. Should his vehicle be using electromagnetic propulsion systems or antiradiation magnetic shielding, on the other hand, he may be exposed to a magnetic field of tens of thousands of gauss. The effect on man in either instance is not clearly established. A health survey of personnel exposed to an almost magnetically quiet environment for most of their working day (such as is found working within degaussing coils) revealed no problems associated with the environment (Beischer, 1962). However, during exposure to fields of value below 50 gamma, significant effects have been observed in flicker fusion and brightness discrimination (Busby, 1967a).

At the other end of the spectrum, visual and even taste and pain sensations have been demonstrated by Beischer (1962) with exposures above the 20-kG range with alternating fields, although no sensations were observed with exposures in nonchanging fields up to 20 kG. Beischer also claims that no ill effects should be expected with exposures to less than 5 kG for less than three days per year per man. At very high levels of exposure (up to 100 kG for 24 h in spider monkeys) disturbances of cardiac and neurological function have been observed (Beischer, quoted by Busby, 1967a). These studies showed a shift in the electroencephalogram to higher frequencies, along with considerable increase in the brain potential. The electrocardiogram showed a decreased heart rate, increased sinus arrythmia, and augmentation of the T-wave. No gross pathology was observed. A variety of other findings has been reported in animals, and in isolated organs, including arrythmia, decreased force of ventricular contraction, and lesions of the adrenal cortex (Space Science Board, 1968b), but in several of these studies a clear cause-and-effect relation cannot be definitely established. While the problem of altered magnetic fields would seem to be less important than that of, say, high-*Z* particles, prolonged exposure to reduced or increased fields cannot as yet be dismissed as presenting no possible hazard.

SUMMARY

In summation, the most significant physiological effect of prolonged spaceflight, if preventive measures are inadequate, is likely to be physiological deconditioning induced by a combination of weightlessness and confinement. Although other disuse effects may be observed on metabolic and neuroendocrine function, the effects of deconditioning will be most important at re-entry when acceleration will place a heavy strain on the system. It seems probable that in space physiological function will change progressively with time until some new steady state is reached appropriate to that environment, but, because many such functions will interact, the final effect is not easily predictable. As far as can be determined, however, with suitable preventive measures already feasible and assuming that relative unknowns such as high-*Z* particles do not prove to be insuperable hazards, the physiological response presents no absolute bar to prolonged space missions.

GENERAL MEDICAL FACTORS

Clinical medical problems in space, as on earth, may be considered in two general categories: those resulting from accidents, failures in protective and supportive systems, or environmental hazards and those occurring "naturally," such as diseases. In both cases, mission planners have given and should continue to give primary attention to prevention—to identify possible causes of accidents and to seek ways to minimize them; to engineer and test systems for high reliability and to build in redundancy; to define environmental hazards and incorporate protective measures; and to prevent the occurrence of illnesses through preflight medical selection and isolation and on-board measures. Nevertheless, despite all efforts toward prevention, it is unlikely that all medical problems could be avoided on a mission of long duration. Consequently, careful thought, consultation, and research in cases where data are not already available must be given to identifying the medical problems that are most likely to occur and that are possible and to means to manage them in space. The more likely problems should naturally be given preferential attention over the less likely ones, but this should not result in the latter being overlooked or assumed not to exist.

The following two subsections briefly summarize the types of medical problem thought possible in long-duration spaceflight. Assessment in any but very general terms of the likelihood of each must await the detailed consideration called for above.

MEDICAL PROBLEMS FROM HAZARDS OF SPACE OPERATIONS

Medical problems that might result from accidents, systems failures, and environmental hazards are summarized below.

Injuries from mechanical forces are considered potentially the most common medical problem from space operational hazards. While some may prove peculiar to the space environment, mechanical injuries of all types and severity, requiring from simple first aid to major surgical treatment, are conceivable.

Possible *burns* in space derive from thermal, electrical, and chemical contacts. Even a small fire or minimal release of a strong chemical in a confined spacecraft atmosphere could have disastrous consequences, especially in damage to the respiratory tract; optimal methods of treatment remain to be identified.

Heat disorders, resulting from systems malfunctions or failure of the pressure suit to provide adequate ventilation during EVA, might include acute heat fatigue, heat syncope, water and salt depletion, heat exhaustion, heat hyperpyrexia, and heat rash.

The likelihood of *cold injury and hypothermia* in space is presently considered quite low, barring systems malfunctions.

Injuries from *explosive decompression* include the disruption, mainly of lung tissues, from gaseous overdistension, and mechanical injuries from bodily displacement or objects displaced by decompression. Calculations predict that decompression of any cabin atmosphere used in the space program to a vacuum while respiratory passages are closed could produce disruption of lung tissue with possibly fatal hemorrhage in the lungs or pneumothorax or formation of bubble emboli. Medical measures indicated if this event occurs in space remain a topic for study.

Provided that preoxygenation is of adequate duration, the risk of *decompression sickness* should be extremely low during EVA and transfer operations, which require decompression from an inert-gas atmosphere (Roth, 1967b), but might be greater in an emergency decompression situation.

Acute hypoxia, possibly aggravated by ebullism (the vaporization of body fluids at ambient pressures below 47 mm Hg), may always be a major potential medical emergency in space. Survival and rapid recovery may depend on the immediate application of resuscitative techniques and on measures to control posthypoxic cerebral edema, which appears to be largely responsible for the slow recovery, permanent neurological sequelae, and often delayed death after exposure to severe hypoxia.

The *ebullism syndrome* is a postulated medical problem caused by bubble emboli delayed in their reabsorption after recompression by contained inert gas, and possibly carbon dioxide, which enter vapor bubbles from body fluids during prolonged ebullism and subsequent recompression (Roth, 1967b).

Meteoroid penetration of a spacecraft cabin wall will conceivably create flash, burn, blast, and mechanical injury from the oxidative explosion of vaporized meteoroid and wall, ejection of molten and hot fragments into the cabin, and disruption of the spacecraft interior. The likelihood of such an event does not seem great on the basis of data on the abundances of meteoroid particles in space.

The effects of prolonged exposure to *abnormal atmospheric mixes or pressures*, particularly to 100 percent oxygen at high partial pressures, could be serious (e.g., Space Science Board, 1967). However, the planned atmosphere for Skylab (70 percent O_2, 30 percent N_2 at 5 psi) and similar atmospheres, possibly at higher pressures, under study for later missions should forestall such problems.

Aerotitis media and aerosinusitis, caused either by a change in ambient pressure or by oxygen absorption from the middle ear or sinus cavities after breathing pure oxygen (during EVA, for example), will probably always be potentially common, although not serious, medical problems in space. However, associated pain or medication used for decongestion could conceivably affect performance in a critical mission phase. This is but one example of a medical problem that dictates the need for first applying therapeutic measures that do not include medication and then, if medication has to be used, it must have maximum effectiveness and minimum side effects.

Atmospheric particles and droplets inadvertently introduced into confined, weightless environments in spacecraft could present serious hazards, depending on their physical, chemical, and microbiological properties. Possible medical effects include irritation and injury of the eyes and the respiratory passages and blockage of a respiratory passage by an aspirated solid particle.

The potential for medical problems from *trace atmospheric contaminants* should be virtually eliminated in advanced space systems. For the present, however, attention should still be given to identifying and managing medical problems that could occur under exceptional circumstances, such as release of pyrrolysis products from an overheated electrical circuit or failure of air-conditioning systems to function properly (Space Science Board, 1968a).

The risk of acute or chronic exposure to *toxic level of carbon dioxide* will probably always exist. Here questions arise concerning the medical effects of prolonged exposure to higher than normal levels, the effects of sudden withdrawal of carbon dioxide, and the ability to increase carbon dioxide tolerance.

Serious acute effects of *ionizing and nonionizing radiation* should not be suffered in space operations if adequate precautions are taken, particularly with respect to ultraviolet and solar-flare radiation and radioactive sources on spacecraft (Langham, 1967; Space Science Board, 1970b). However, great interest remains focused on high-Z particles (see previous section), prediction of solar flares, and chronic effects of protracted exposure to low levels of radiation.

Urinary calculus is included in this list if only to point out a possible need for measures to prevent its formation if excreted products of bone reabsorption are elevated. Preventive measures may be directed toward diminishing loss of calcium and phosphates in urine and better understanding of the mechanisms of urinary calculus formation.

NATURALLY OCCURRING DISEASES

The continued application of strict medical criteria in flight-crew selection and preflight isolation should keep the potential incidence of most infectious and noninfectious illnesses that could require medical attention in space to exceptionally low levels. Whereas some illnesses, such as acute appendicitis, can indeed be called "naturally occurring," others, such as peptic ulceration and severe anxiety, could be initiated or aggravated by the environmental and operational conditions to which astronauts are subjected. In these respects, it is of great predictive value to study the potential for illness both in initially healthy, large populations of individuals with ages comparable with space crews and in small groups of individuals living and working under relatively confined conditions for prolonged periods of time. In addition, the prospect that scientist-passengers may participate in future spaceflights, for example on the shuttle or space station, raises interesting possibilities for less stringent medical requirements for selection. Such persons might well fall outside the normal medical and physical characteristics of astronauts, and preflight isolation might not be compatible with the conduct of their experiments. This prospect should stimulate careful re-evaluation of current medical requirements to determine which, if any, medical or physiological deviations could be tolerated inflight, and flight experience with scientist-passengers could be utilized in developing the medical requirements for missions of long duration.

Ellingson *et al.* (1969) have pointed out that, as expected from numerous altitude chamber and other studies, the environmental conditions to which crews have been exposed in space do not appear either to have lowered resistance to infections with organisms normally present or to have enhanced the pathogenicity of these organisms. However, these investigators do point out that further investigation is needed to be assured that such events will not occur.

Interestingly, observations to date on confined populations indicate that adequate hygienic measures in space crews should minimize buildup and transfer of microorganisms among individuals. If hygiene is poor, a variety of *skin infections* and an enhanced likelihood of infection of even minor wounds can be expected. This raises the question of whether potentially pathogenic organisms such as *Staphylococcus aureus* should be eliminated from members of a space crew prior to their embarking on a long-term space mission.

The likelihood of carrying *respiratory and gastrointestinal viral illnesses* on spacecraft when preflight isolation is inadequate has been emphasized (Space Science Board, 1970a). Although some effect of weightlessness on the airborne spread of infection, such as droplets created in coughing or released from a suppurating wound, has been postulated (Space Science Board, 1967, p. 113), actual studies have not been conducted in this area. Finally, one may expect that illnesses may result when crews who have been isolated from the repeated immunological stimuli that result from contacts with many people interchange, receive new members, or visit isolated manned space stations.

Even though astronauts must meet high standards of mental and physical health, it must be agreed that they will not be totally invulnerable to the great number of stresses imposed on them during long-term space missions. Accordingly, however remote, the possibility of various *stress illnesses*, such as *peptic ulceration, spastic colitis, neurodermatitis, cardiac arrhythmia, severe anxiety,* and *mental disorders,* must be considered in future mission planning. This area requires intensive study, particularly from predictive standpoints. Existing data in the medical literature will be helpful here but may not apply to all the special conditions of spaceflight.

Allergic reactions, systemic and local in nature, must be considered possible in space. Not all medications can be pretested on astronauts. There will probably always be a risk of developing allergies to food and other allergenic agents in spacecraft during long-term missions.

Preflight dental care and inflight dental hygiene should minimize the probability of *dental problems.* Even so, it is believed the provision should be made for treating caries and a variety of other dental problems in space. This subject has already received attention (Ferguson and Hartley, 1966; Rothe and Hartley, 1967).

Finally, the potential occurrence in space of one of the commonest of all surgical emergencies—*acute appendicitis*—must be considered. A predictive study may indicate the desirability of an appendectomy prior to long-duration missions.

Careful attention should be given to the possible effects that cardiovascular *adaptations to weightlessness* might have on the susceptibility to, or the severity of, medical problems in space. As suggested earlier, it appears that blood volume decreases and the capacity for orthostatic venous pooling increases during prolonged exposure to weightlessness. How these adaptations, if not prevented or if left uncompensated, might affect the occurrence of hemorrhagic and nonhemorrhagic vasomotor collapse, heat disorders, injuries, and other medical problems during exposures to various *g* levels remains to be determined.

GENERAL ASPECTS OF MEDICAL MANAGEMENT IN SPACE

Space clinical medicine is directed at preventing the occurrence of medical problems in space and at restoring an astronaut suffering from a medical problem to optimal functional capability as quickly as possible. To date, relatively little attention has been given to providing for the management of possible medical problems during space missions. Rightly so, for few problems, short of those from catastrophic events, have been expected in missions of such short duration with only one-, two-, and three-man crews. Except for the lunar missions, return to earth for medical care could have been accomplished quickly. Weight and volume restrictions have allowed for only minimum medical provisions on spacecraft. Accordingly, to train space crews in more than simple first aid would have been unjustified. However, it must be assumed that the scope of responsibility of clinical medicine will increase with mission distance, duration, and complexity and with crew size. To this end, much effort will be spent in coming years on identifying potential problems from hazards of space operations and so-called naturally occurring illnesses and on providing the optimum means and competence for their management on spacecraft.

Few authors have specifically undertaken to define the future scope of space clinical medicine. Busby (1967b, 1968) has written extensively on the management in space of medical problems thought possible from hazards of space operations. Wittmer (1967) has described a systematic approach to the identification of on-board medical and therapeutic items for manned spaceflight. Hoffman and Kontaratos

(1967) have suggested a broad medical program in support of advanced manned missions. The Space Science Board (1970a) has conducted an in-depth study on infectious diseases in spaceflight. In the Soviet literature, Bayevskiy (1966) has given broad attention to space clinical medicine of the future, whereas Yaroshenko and co-workers (1967) have dealt with predicting mathematically the frequency of certain medical problems as related to mission duration and crew size. All authors have noted that, barring the unforeseen, medical problems thought possible in space also occur in earth environments and will receive essentially the same medical management in space as on earth. They do point out that the space environment not only makes it necessary to adapt many conventional diagnostic and therapeutic techniques for use under weightless and confined conditions, but also that these conditions could alter the severity of some medical problems and the effectiveness of treatment. These considerations, coupled with constraints that will continue to be placed on the size of medical facilities and the numbers of medically trained personnel on board future spacecraft, dictate the desirability of a systematic, integrated, logical approach to meeting the expanding responsibilities that will be demanded of clinical medicine in future space exploration. This will require continued efforts to identify and predict the incidence of possible injuries and illnesses in space, initiation of space-oriented research and literature searches directed at establishing optimal measures for managing medical problems in space, selection and development of hardware and techniques required for diagnosis and treatment in space, and determination and assurance of the medical competence necessary on spacecraft.

Although most medical problems, especially those from operational hazards, should be readily diagnosable, some may require the application of various techniques to make or confirm diagnosis. Table 1 lists diagnostic techniques that might be considered as candidates for use in space. These and no doubt others should be evaluated in the light of anticipated medical problems and other factors to determine which are necessary or desirable for inclusion in long-duration missions. Basically, these techniques derive from traditionally accepted methods of medical examination on earth. Most will require only minor modifications to minimize the weight and volume of instruments and the possibility of atmospheric contamination. Interestingly, those sophisticated techniques that require development of advanced hardware will be determined by such factors as crew size and mission distance, duration, and complexity. Diagnostic tech-

TABLE 1 Diagnostic Techniques

Bacterial culture and sensitivity determination	Fluorescein staining of eye
Blood hemoglobin determination	Hematocrit determination
Blood pressure determinations	Indirect laryngoscopy
Systemic arterial	Microscopic studies
Peripheral venous	Blood
Body temperature determinations	Urine
Oral	Ophthalmoscopy
Rectal	Otoscopy
Electrocardiography	pH determinations
Electroencephalography	Blood
Electrolyte studies	Urine
Blood	Rhinoscopy
Urine	X-ray studies

niques will require extensive testing in ground-based and orbiting laboratories before they are approved for long-term missions. Communication by telemetry and television with medical facilities and physicians on earth to analyze biomedical recordings and data and to consult will probably always play a major role in the diagnosis and treatment of medical problems in space.

Definitive and supportive therapeutic measures that might be considered for advanced spacecraft, particularly given a physician-astronaut and suitable medical facilities on board, are listed in Table 2. Here again, evaluation and judgment will be required to determine which should be included in long-duration missions. The manner of carrying out therapeutic measures in space will, in general, be no different from that on earth. Some measures, such as parenteral infusion and surgical procedures, will require adaptation to the weightless environment. The selection of therapeutic materials and instruments must be made on the bases of versatility and flexibility, as well as weight, power, and volume allowances. For example, fluids for intravenous infusion can be constituted as needed from stored sterile water, which is also available for drinking in a contingency situation, and lightweight surgical instruments can be designed to have multiple uses.

Types of drugs and intravenous fluids that might be indicated for management of medical problems are listed in Tables 3 and 4. Important factors determining drug selection will be single and multiple actions and usefulness, specific actions and undesirable side effects, numbers of modes of administration, shelf-life and stability, and absence of harmful effects peculiar to the space environment. Individual

TABLE 2 Definitive and Supportive Therapeutic Measures

- Airway maintenance
  - Oral
  - Endotracheal
  - Tracheostomy
  - Cricothyroid membrane puncture
- Aspiration procedures
  - Aspiration of hematoma or other fluid accumulations
  - Thoracentesis
  - Pericardiocentesis
  - Paracentesis of tympanic membrane
- Blood transfer between astronauts
- Cold application
- Drug administration
  - Oral
  - Topical
  - Local and regional
  - Systemic (intramuscular and intravenous)
- Eye patching
- Foreign body removal from eye, nose, and larynx
- Heat application
- Hyperbaric recompression
- Hypothermia induction
- Immobilization of body part
  - Temporary
  - Indefinite duration
- Incision and drainage
- Intravenous fluid administration
- Irrigation of skin, eye, and upper respiratory tract
- Laparotomy
- Myringotomy
- Nasogastric intubation for aspiration and feeding
- Oxygen administration
  - Ambient pressure
  - Intermittent positive pressure
- Pinch grafting
- Politzerization
- Suction
  - Upper gastrointestinal tract
  - Respiratory tract
- Tourniquet application
- Trephining
- Urinary bladder catheterization
  - Repeated
  - Indwelling
- Wound management
  - Antiseptic preparation
  - Debridement
  - Blood vessel ligature
  - Wound closure
  - Dressing

responses to the drugs that are most likely to be used in space should be tested before space missions, not only to identify idiosyncrasies necessitating selection of alternative drugs but also to determine optimal dosages. Certain antibacterial drugs might be indicated after determining, in the preflight period, the drug sensitivities of skin, respiratory tract, and intestinal pathogens that might cause primary or secondary infections.

MEDICAL COMPETENCE ON SPACECRAFT

Finally, consideration must be given to the level of medical competence necessary to optimal management of medical problems in space. It is readily apparent that an astronaut trained to diagnose and treat common anticipated medical problems would at best be a poor substitute for a physician-astronaut who has acquired a high degree of clinical judgment and technical skill over many years of academic

TABLE 3 Types of Drugs

Analgesic	Antipyretic
Anesthetic	Antitussive
Topical (eye, skin, respiratory mucous membranes)	Bland ointment
Regional	Bronchodilator
Antiarrythmic	Carbonic anhydrase inhibitor
Antibacterial	Cardiac glycoside
Antiseptic (oral, skin, wound)	Central nervous system stimulant/depressant
Bacteriostatic (eye, skin, urinary)	Corticosteroid (steroid)
Antibiotic (topical skin, outer ear canal and eye; systemic)	Decongestant
Antibiotic/steroid	Topical
Antacid	Orally administered
Anticoagulant	Dehydrating agent (osmotic diuretic)
Anticonvulsant	Hemostatic
Antidiarrheal	Hypnotic
Antiemetic	Miotic
Antimotion sickness	Mydriatic
Antiradiation sickness	Shivering suppressant
Antifungal	Sympathetic blocking agent
Topical	Tranquilizer
Systemic	Vasopressor
Antihistamine	Vasodilator
Antihypertensive	
Anti-inflammatory	
Topical	
Systemic	

TABLE 4 Types of Intravenous Fluids

- Saline
- Glucose in water
- Ringer's lactate solution
- Bicarbonate solution
- Calcium gluconate solution
- Supplemental potassium solution
- Plasma-expanding agent (e.g., dextran, blood plasma)
- Fresh whole blood
  - Carried into space
  - Transferred between compatible astronauts
- Frozen blood
- Blood-formed element concentrates (e.g., red blood cells, white blood cells, platelets, bone marrow)
- Mannitol solution

training and continuing work in clinical medicine. However, there must be sound justification for having a physician-astronaut and medical facilities on spacecraft. Determining factors are mission distance, duration, and complexity; crew size; magnitudes of hazards associated with the mission; medical facilities that can be taken into space; and requirement for intensive, direct, physiological monitoring during missions. It should also be noted that a physician-astronaut must be trained to perform duties, such as management of life-support systems and research, that will make him a continuously useful member of the crew. Whether or not a physician-astronaut is on board, it is considered mandatory to train one or more of the crew members who will be least exposed to operational hazards in the basics of medical management in space.

A physician-astronaut should be specialized not only in aerospace medicine but also have an extensive general medical and surgical background. He should be a keen monitor of physiological functioning. Establishing an adequate program for training of physician-astronauts will undoubtedly be a major undertaking in space clinical medicine.

MEASUREMENT AND EVALUATION OF PHYSIOLOGICAL RESPONSES IN FLIGHT

In man's first difficult steps in space, there were fundamental questions about his ability to survive let alone perform well in exceedingly demanding tasks (Bedwell and Strughold, 1964; Flaherty, 1961; Livingston *et al.*, 1962). Medical monitoring was thus conceived in the very limited frame of vital signs in cardiac and respiratory systems. Concomitantly, astronauts received few assignments that tested either physical or psychological capacities to extremes—or even to useful limits. In later missions, with survival capacity established, task requirements were increased exponentially (Berry, 1970). Although both U.S. and Soviet manned missions have been highly successful in demonstrating man's ability effectively to control complex mechanical systems, a disturbing hiatus has developed between empiric awareness of man's capacities and deficiencies as an astronaut, on the one hand, and, on the other, a lack of actual baselines that would give a quantitative measure for comprehensive evaluation of all major physiological systems.

Flights to date have been short and cover relatively brief periods of transition to weightlessness. However, many physiological adaptations undoubtedly occur in this period. Beyond these early days or weeks, slower trends would be anticipated, either toward recovery of full terrestrial capabilities, toward slow and probably subtle degradation of physical and psychophysiological performance, or toward a plateau of capabilities substantially below those on earth but adequate for space. Many of the changes would be expected to occur at the cellular or even molecular level and hence would not normally be detected unless overt symptoms developed. And yet, long-duration missions presuppose man's ability to perform indefinitely at a high level physically and mentally (President's Science Advisory Committee, 1969). In this context, systems and techniques to acquire and analyze biomedical data must meet pressing needs. Physiological monitoring of similar problems in such areas as the submarine service may not be comparable, since so little is known about the specific effects of the space environment.

EVOLUTION OF BIOINSTRUMENTATION AND BIOANALYSIS FOR SPACEFLIGHT MEASUREMENTS

The first medical measurements of astronauts and cosmonauts followed classical traditions in experimental concepts and were constrained by limitations in bioinstrumentation (Henry *et al.*, 1962). Sensors and transducers were constructed in the image of more than two centuries of laboratory research. The test subject was often a captive of bulky and obstructive instrumentation. For the astronaut, biomedical data acquisition was thus self-limited by more urgent mission considerations and by failure of the life scientist to produce instrumentation compatible with the astronaut's ever-growing role in operating the spacecraft. At the core of the problem have been semantic difficulties between life scientists and engineers. Life scientists have been diffident in accepting the power of mathematical and engineering tools at all stages of biological experimentation and data analysis (Dickson and Brown, 1969). The engineer has tended not to take full account of the complexity in the organization of living systems, to the detriment of solutions of instrumentation problems and of his mathematical formulation of models of living systems. Yet, both physical and life scientists must achieve truly collaborative relations in unique and imperative ways if there is to be efficient monitoring of man in the equally unique environment of space.

The measurements to be made will involve development of instrumentation, its extensive testing and application in terrestrial biomedical problems, and collection of baseline data prior to flight (Weltman *et al.*, 1968). The majority of this needed instrumentation does not now exist. Where initial developments have occurred, the new sensors, novel acquisition systems, and new approaches in data analysis all indicate a growing utilization of a wide variety of technologies from aerospace engineering (Walter *et al.,* 1967).

To achieve artifact-free recording in performing subjects, emphasis should be placed on noninterference methods of data acquisition, such as by nonadhesive skin contacts, from central nervous, cardiovascular, ocular, neuromuscular, and autonomic nervous systems. Amplifiers may be incorporated into the sensor, which thus becomes an electrode-amplifier, impervious to much of the electrical interference that is so deleterious to conventional electrodes with high-impedance connecting leads. Telemetry devices can also be made integral with these electrode-amplifiers, thus providing a completely self-contained sensing system. In long-duration missions, repeated daily testing will demand convenient and reliable attachment and removal of body-surface sensors (Kado and Adey, 1968).

Acquisition of biomedical data on magnetic tape has caused a veritable revolution in research instrumentation comparable to the introduction of the smoked drum. It has provided a storage medium of very high reliability under field conditions. It is noteworthy that as recently as the flights of the chimpanzees Ham and Enos in the Mercury program, no suitable physiological tape recording systems were available, and flight data were recorded optically (Meehan *et al.,* 1963). Most important, tape recording has provided convenient intermediate storage of data prior to computer analysis. However, tape recorders currently available for spaceflight do not meet all probable needs for biomedical monitoring in prolonged missions. Thus, much further development is needed in multichannel physiological recorders (approximate data bandwidth 0.2 to 100 Hz) with a recording time in excess of 100 h. Data from these recorders would be returned at the end of the mission. However, in prolonged earth-orbital missions with orbit times of about 90 min, there will be a requirement for continuous recording of data and rapid playback during ground-station encounter. The latter recorders would challenge the state of the art if they included even low-resolution video data.

APPROACH TO PHYSIOLOGICAL MEASUREMENTS IN SPACE

Without measurements that directly evaluate functions in an organ or in a physiological system, only its functional integrity or pathology can normally be inferred. Conversely, measurements will be of value only to the extent that they are made in systems, which, by good fortune, are correctly inferred to be susceptible to environmental manipulation. It cannot be expected that even the major physiological systems will be monitored in sufficient detail, or with sufficient continuity, for sheer serendipity to disclose all significant perturbations. There is thus a circular quality to philosophies of biomedical investigation in manned spaceflight: Very little information is available; to gather more information, opportunities are needed for skilled observation in experiments that will continue to be designed intuitively, until such time as baselines are increased substantially in breadth and depth.

There are certain systems in which first observations have indicated changes during weightlessness or in which susceptibility to weightlessness can be strongly inferred. These include the cardiovascular, central nervous, musculoskeletal, metabolic, and endocrine systems.

It should be emphasized that it is neither feasible nor desirable to investigate a single major physiological system without regard to concomitant effects in other systems. This in itself poses challenges in instrumentation for mutually compatible measurements, particularly since the focus of biomedical interest shifts sharply as exposure to weightlessness extends beyond a transition period. This transition period is estimated from minutes to days in different aspects. Parameters such as cardiovascular and central-nervous responses to the brief but overwhelming stimuli of the launch phase are not necessarily those in which interest lies in these same systems during prolonged weightlessness. Yet it is in consideration of the former that the great traditions have been laid in aeronautical medical research. They have determined a whole era of physiological instrumentation. They not unnaturally pre-empted design considerations in early instrumentation for spaceflights, particularly where those were of short duration and concerned with man's ability to withstand stresses of launch and reentry. It may be argued that this preoccupation has significantly delayed vigorous pursuit of new lines of instrumentation for use in spaceflight. These needs are now paramount for studies of prolonged exposure to the space environment.

Hospital clinical facilities possess the capability for many measurements in addition to those just noted. An inflight clinical laboratory should also be equipped to make some of those additional measurements. Exactly which ones should be the subject of a serious and continuing study conducted by NASA and its medical consultants

(Vinograd, 1966). For example, a water and electrolyte imbalance might require measurement of hormone blood levels to establish its etiology. An infection would demand cultures to identify the causative organism. Dozens of such examples of possible measurements could be listed; qualified clinicians must create such a list and estimate the likelihood that a particular measurement will be required. Given such a list of priorities, the number of measurement capabilities actually included will depend on the availability of needed measuring instruments and the anticipated technical developments in methods for making single, accurate analyses (e.g., flame photometry, chromatography).

To the biomedical scientist, accustomed to frequent and often radical manipulation of his experiment in clinic or laboratory, his first encounter with the difficulties of achieving necessary reliability in a partially or completely automated system for an essentially simple spaceflight experiment may be most discouraging. These experiences have led to agreement on certain philosophies that offer constructive guidelines for instrumentation of future biomedical investigations in space (Vinograd, 1966). First, it has become clear that the highest order of reliability is an inherent requirement in all biomedical instrumentation for spaceflight, whether it is to be used by man on man or by man in measurements on other living forms. The cost of failure is unacceptably high. Second, past measurements that have involved numerous points of interaction with the vehicle have been replaced by the modular concept of self-contained instrument packages for studies in man. This system should allow continued flexibility for the experimenter to modify and update his experiment in the long years of lead time that typically precede its flight.

Biomedical data-acquisition systems may be classified into four groups.

Data-Acquisition Systems Attached to Body Surfaces In this category are included EEG, EOG, EKG, EMG, and GSR recordings, together with sensors for respiration, skin temperature, and blood pressure. These data have both immediate and long-term significance and consequently are necessary in forms suitable for both telemetry and inflight recording. Such data are necessary as indices of diurnal rhythms and should thus be sensed with devices that do not interfere with sleep nor with required tasks.

It may be argued that medical requirements should be made only at designated locations and times, even on long-duration missions, but a strong case can be made for continuity of measurements over several days at recurrent intervals in long missions. This philosophy would argue against restricting acquisition of data on alertness and task performance to measures made for medical purposes only or to measurements made in the absence of appropriate motivating factors.

Sampling for Metabolic and Endocrine Studies The level of biochemical and endocrine studies that might be possible in spaceflight will depend in part on the presence of scientist- or physician-astronauts. Their presence should be mandatory to make reliable inflight estimates of hormones and metabolites in body fluids on at least a significant portion of initial long-duration missions. Presence of such a professional would permit sampling of blood without risk to the subject: lack of inflight blood samples can no longer be justified on grounds of potential hazard or interference with flight tasks. In the absence of a scientist-astronaut, many needed biochemical measurements can be performed by astronauts with suitable training; these should include estimates of urinary electrolytes, steroids, and catecholamines. Instrumentation to measure steroids in this way is not currently available.

Acquisition of Data for Analysis Postflight Much useful information contained on magnetic tapes is recorded in a form not suitable for telemetry and, indeed, may not be needed inflight for prediction of crew status. Postflight analysis of these data will often involve protracted computation. Certain biochemical and endocrine analyses will probably always be performed in terrestrial laboratories, rather than inflight, by reason of procedural complexities, and ground-based analyses will be desirable in many cases to corroborate estimates made inflight. For example, lyophilization will fully preserve urine and blood and allow intensive postflight analysis.

The Automated Physical Examination Psychosomatic medicine emphasizes the interaction between mental state and bodily function. Presumably the morale of the crew and the mental health of each astronaut in it will be monitored at regular intervals. Consideration is being given to installation of an on-board console from which a daily report of the physical and mental status of each astronaut can be obtained. Ideally, this console would televise the astronaut's face, permit voice communication with the ground, and include an apparatus for testing motor coordination, reaction time, etc. More relevant here, the astronaut would attach sensors to himself through which his EKG, body temperature, EEG, muscle strength, blood pressure and flow (e.g., finger plethysmograph), and perhaps other dynamic measures of function would be recorded and transmitted automatically to the ground. A scheduled routine to provide both baseline data at rest and the changes taking place with mild stress (e.g., isometric exercise) should be worked out. This short, automated physical examination would evaluate both the psychological status (verbal responses to questions, performance tasks) and the bodily functions, including response to physical stress. Adjuncts to the simple examination should also be provided, again after further careful and continuing evaluations by medical consultants. A diagnostic x-ray machine may not be feasible in the absence of a physician-astronaut, but in his presence it would be a reliable aid. Teaching all crew members to conduct a complete physical examination, providing them with the tools to do so (e.g., stethoscope, ophthalmoscope), and training them to cooperate with ground physicians may be the only feasible possibility on long missions lacking a qualified physician. It would be advisable for an outside panel of experts to re-examine the entire problem of on-board measurements in the light of the long-duration mission requirement.

DATA-ANALYSIS PROCEDURES

In biological phenomena, significance attaches only to perturbations beyond accepted limits. There may be long periods in which electrophysiological data are within designated ranges. It is within the current state of computer arts to process such data inflight and to establish their relation to accepted baselines. Deviations beyond these limits can be telemetered to ground-control stations. Optimally, all monitoring procedures would be done from earth, but demands in telemetry transmission channels would be exorbitant for numerous channels of normal data for long periods.

Flight computers can also be employed to recognize patterns in multivariate parameters, particularly where the number of parameters exceeds those readily estimated by the human observer. This preprocessing of data by special-purpose devices can greatly reduce bandwidth requirements for spacecraft telemetry systems which will be taxed by attempts to transmit large volumes of unselected data from several subjects in the current pulse-coded-modulation mode, even with the capabilities of the Apollo *S*-band transponder system. It is in synthesis and analysis of these large volumes of data that sophisticated computer applications will be necessary in postflight periods. These analyses can be most fruitful in revealing patterns not detectable in data from individual subjects involving very subtle trends, and they are required procedures to obtain estimates of common factors in group baselines. A study by the National Institutes of Health has provided such baselines for EKG data (Caceres, 1964), and a NASA-supported study has provided the first such library of normal EEG data from astronaut candidates (Walter *et al.*, 1967). However, there is an urgent need for development of both special-purpose flight computers and pattern-recognition capabilities in large terrestrial computers. No federal agency is currently supporting their development, and it is manifest that their usefulness considerably transcends the aerospace field.

EVALUATION OF BIOMEDICAL DATA

Who should have access to the data, and who should take action on it? Routine measurements on all body systems should be transmitted automatically to earth and be evaluated there. Feedback to the crew should be limited to a simple statement (e.g., "You are in good shape") or none at all. Such a procedure would ensure the reliability of the measurements, de-emphasize crew concerns with health problems, and place the responsibility for medical decisions where it belongs—on the ground. A request for nonroutine additional measurements on an astronaut would signal potential danger to the crew and provide them with immediate access to physiological data. They would detect deviations from the normal values encountered in previous practice sessions, but any decisions that derive from analysis of these data should again come from the ground.

It is difficult to imagine a situation where, given proper communication facilities, medical decisions of any importance would optimally be made on board the spacecraft.

RECOMMENDATIONS

1. Extensive ground-based research and subsequent inflight research with man and animals should be pursued diligently over the full range of physiologically deconditioning factors. An understanding of the

course of deconditioning over two years, its mechanisms, and consequences, together with validation of effective countermeasures as necessary, must be in hand before man may be permitted to engage in long-duration space missions. Inflight research is visualized to include only definitive experiments that cannot be performed on the ground; cautious and conservative use of the incremental approach with man; possible use of human surrogates, especially monkeys, for long-duration studies in man-tended orbital stations, which will remain in space as crews rotate; and, perhaps, unmanned animal flights to investigate discrete problems.

2. A long-duration, ground-based investigation of the immediate and cumulative effects of high-*Z* particles should be undertaken as soon as suitable accelerators are available, provided that studies in the interim support present hypotheses on the nature and severity of this hazard. At the present time it appears that, like deconditioning, a thorough understanding of high-*Z* particle effects and availability of proper protection must precede any participation of man in long-duration flights beyond the magnetosphere.

3. Ground-based research on phase shifts of circadian rhythms and desynchronosis should continue to assess their effects on performance and well-being. In forthcoming manned flights, investigators should be alert to signs that might suggest added environmental effects on circadian rhythms. In addition, the biological effects of high magnetic fields should continue to receive study.

4. The health and safety of crew members in long-duration missions will require continuing research and effort on the part of clinical medicine to identify potential hazards, illnesses, and injuries. The work should include determination of the probability of occurrence of specific medical problems, development of preventive procedures and countermeasures, and determination of optimal means of diagnosis and treatment including the amount of on-board medical competence required. Special attention should be given to procedures for coordinating on-board efforts with ground-based medical advice and consultation, especially in the case of emergencies and unusual exigencies.

5. Data from astronauts in short- and intermediate-duration spaceflights should be assembled and analyzed in order to establish what deviations in physical, physiological, psychological, and chemical measurements on man in space best predict reductions in his well-being. Such flights are visualized as unusual practical opportunities (a) to provide information essential for decisions on what constitute

significant deviations, (b) to identify potential problems in a reasonable sample of men exposed to the space environment, (c) to develop the optimal techniques for acquiring the maximum amount of useful biological information from each astronaut, and (d) to test measurement devices to be carried on long-duration missions.

6. Automated physical examinations and automated biochemical tests should be developed on the basis of the above information and administered to crew members preflight, inflight, and postflight to monitor the biological parameters identified as critical to the well-being of astronauts during prolonged flights. With appropriate consultation from biomedical scientists and clinicians it should be possible to construct for self-administration a suitable and feasible assembly of automated tests for use by astronauts on long-duration flights.

3 Physical Factors

Physical anthropology and anthropometry have demonstrated that men differ significantly in somatotype or body build, in height, weight, length of arms and legs, crown to rump height, width of hips and shoulders, interocular distance, shape and size of head, and in various other body dimensions and proportions. The particular physical characteristics of an individual are determined by, or vary as a function of, heredity, glandular and physiological functioning, age, sex, ethnic and cultural group, occupation, special training, diet, and physical environment.

Even astronauts, although highly selected on a physical basis thus far, are not uniform in physical characteristics nor are they equally adaptable to the physical features of their environment, including the working and resting spaces they occupy and their immediate personal effects such as space suits, shoes, helmets, and other items of equipment. The height and location of the indicators they observe, the controls they manipulate, and their tools and living space may require considerable adaptation and adjustment on the part of astronauts. If any of these factors is unsuitable, it may lead not only to inefficiency in performance but to cumulative annoyance which, coupled with other concerns, may have a seriously detrimental

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effect over prolonged periods of time. The physical circumstances under which astronauts must perform in conditions of weightlessness or partial gravity and the positions in which they must place their bodies, often maintained by physical restraint, add to the difficulties of their adjustment and further complicate the planning of man–machine–environment relationships, especially when these must be maintained for extended periods of time.

Long-duration missions will bring to bear two new elements that will have substantial impact on spacecraft design and operations. The first, just alluded to, is that such missions can exacerbate to the point of intolerability some of the design compromises that proved acceptable for relatively short flights. Second, international participation and the science-oriented crews likely to obtain in long-duration missions can result in greater heterogeneity in physical characteristics; this could affect habitability requirements. Experience with military aircraft such as the C-130 and F-4, designed for a U.S. pilot population and used later with foreign nationals, demonstrated this type of problem.

Although physical dimensions of pilots have been taken into account in the design of limited-volume aircraft, it has usually been done on a standardization basis, using normative data from a limited-range population without necessity of close tolerance levels. Even under these somewhat less than critical conditions individual differences in physical characteristics have usually taken second or third place to other demands, so that comfort or ease of manipulation was often sacrificed and the man–machine relationship was compromised in favor of the machine. Thanks to the adaptability of man, such compromises can often be made to work, but it is seldom empirically determined at what cost or risk to the man involved or to the complete success of the mission.

Unlike aircraft designed to accommodate pilots of more widely varying dimensions and selected in greater number from a much larger pool of men, spacecraft in present use have been designed for a small, known, and fairly homogeneous population. Astronauts have participated as subjects in the design process, and the system has literally been build around them. In the case of early Mercury missions, the spacecraft couch was molded for each astronaut. Despite this, many physical limitations have been imposed upon the astronaut to which the aircraft pilot is not exposed. Initially, due to limited booster capacity, the spacecraft weight, space, and configuration were greatly restricted; bulky space suits and life-support devices imposed physical handicaps and abnormal postures. The later, larger capsules were hardly less cramped with three men and with more life-support and other apparatus on board. In spite of "tailor-made" space suits and personal gear, it could be argued that design has accommodated less to the astronaut than to the aircraft pilot: anthropometric design has concentrated on assuring that the astronaut could see and reach controls and equipment, particularly when in the inflated pressure suit. Some special attention has been given to crew transfer and extravehicular activities. However, inconveniences that tend to reduce crew efficiency and contribute to lack of comfort were tolerated for the sake of expediency.

Physical factors that may be important determinants of man's capability on long-duration missions include over-all and specific body dimensions of both static and dynamic spatial nature. These include provision for bodily comfort in relatively fixed postures and flexibility in man–machine performance relationships and in other reflex and voluntary activity. This means relative freedom of movement and ability to shift positions within the limits of constraint imposed by life-support and other protective gear in the presence of 0 or partial g. Other factors may also be involved, but their relation to the specific, 0 g, capsule environment has not been determined qualitatively and quantitatively: available data on structural and functional characteristics of the body are mainly specific to terrestrial environments and are based largely on measurements of military groups (e.g., Damon, 1955). Long-duration missions will require that all physical factors be taken into account well in advance and prepared for by appropriate research and implementation of preventive measures.

Characteristically, aircraft and spacecraft have been designed to meet rigid physical specifications such as those required by aerodynamic principles; power requirements; thermal, sound, radiation, and magnetic shielding; weight; volume; and control instrumentation. Despite the exercise of some known human engineering principles with respect to the design of instrument panels and controls, there are usually overriding engineering requirements, so that in the man–machine relationship man is often given secondary consideration. This has, in fact, been true since human engineering became a speciality during World War II. Usually the psychologist, physiologist, or human engineer is given the man–machine relationship problem to solve after the basic design features of an instrument or craft have been established on other grounds. Consequently, no matter how competent and dedicated the human engineer, he is apt to end up with too little, too late, or at best be able to modify only slightly some of the features already built into the prototype machinery.

At least in some respects, the physical scientist or engineer has an easier time in meeting his specifications than does the human engineer or bioengineer—the physicochemical properties of material things, such as metals, either have been determined quantitatively or can be worked out to close and fixed tolerance levels by the development of equations and formulas. This is not the case with living things where physical dimensions are subject to much wider individual variations, and where functional capacities have greater baseline fluctuations. Furthermore, one cannot take reckless chances with human life by pushing stresses to the limit of man's endurance, nor can one impose loads of relatively unknown dimensions on a highly variable and reactive dynamic organism when specific goals and accomplishments are at stake. Anthropometry can measure physical characteristics and establish normative data which may be used to select a narrowly specified group. But the physiologist and psychologist are not quite so fortunate with respect to functional characteristics. A given physiological measure may be a partial index of the system from which it comes, but it is subject to fluctuations because of interactions with other physiological systems. The behavior studied by the psychologist is even more difficult to pin down, since it depends on an underlying physiology and in turn can affect the background physiological state as well as more specific functions of the organism.

PHYSICAL VARIATIONS

Some of the sources of variability, and the implications for the design and use of advanced systems, are discussed below. These are only a few of many factors that involve physical features of the environment and physical features of the organism. These may interact and in turn generate physiological and psychological changes which may or may not be beneficial. The goal, of course, is to prevent mismatching of environmental and organismic physical factors, by adapting one to the other.

GROWTH

Increases in the average physical size of crew members can become important if the system has a long development-operational cycle.

This has been a problem in military aircraft, where dimensions that were marginal initially became intolerable when used by later populations that had increased in size. Moreover, population measures may be obtained 5 to 20 years before a system is designed, and a system may have a 10- to 15-year life cycle. This has presented a problem with respect to critical dimensions such as seating height in fighter cockpits; the problem was compounded by new helmet and ejection seat design that added to seating height. An example of the growth that may occur in two to three decades is the increase in height of 0.7 in. and weight of 13 lb between World War I and World War II inductees.

VARIATIONS WITHIN AND BETWEEN INDIVIDUALS

Design typically does not account for the large percentile variations that exist in physical dimensions of "normal"-sized individuals as well as the oversized or undersized within a population. The crew selection process for spaceflight is already rigorous in terms of physical, intellectual, emotional, and skill requirements. It is necessary to determine whether restrictions on physical dimensions should be added to this list as they were in the Mercury and Gemini programs where astronauts' height could not exceed 71 in. If there are no size restrictions, design must be made to accommodate a wider range of individuals; cost and weight will be greater. However, if there are size restrictions, the additional selection criteria may eliminate otherwise highly qualified candidates.

In general, it is desirable to limit the items that call for close tolerance specifications, such as the present pressure suits that must be individually fitted. Rather, sensible population statistics can be used for generalized design to allow most equipment to be used by everyone. Restrictions on size probably should not relate to over-all dimensions such as height but should recognize the large variation among individuals. Restrictions, if any, should be specific, such as shoulder breadth for hatch-sizing.

OCCUPATION

Differences occur between occupational groups in body dimensions and performance capability, probably resulting from a combination of selective and environmental factors (Morgan *et al.*, 1963). Science-oriented crews of the future probably will be more heterogeneous.

AGE

Intellectual functioning as a whole tends to remain relatively constant as a function of age in the population ranges that would be considered for spaceflight. Decrements occur in reasoning and numerical ability but are balanced by increases in verbal ability (Fleishman and Bartlett, 1968). Muscle strength declines, usually at an increasing rate from the late twenties on (Fisher and Birren, 1947). This should not have a significant effect on operations in space because few tasks have, or need to have, brute-strength requirements.

SEX

Changes in maturational and interest patterns tend to create differences between sexes that might be a factor in their ability to function aboard spacecraft. Females tend to have greater verbal ability, while males tend toward greater numerical ability, perception of spatial relations, and strength (Fleishman and Bartlett, 1968). Females are 5 in. shorter and weigh 35 lb less than their male counterparts (30–34 years) and have obvious (and not so obvious) differences in percentiles for various body dimensions (Morgan *et al.*, 1963).

NEW INFORMATION NEEDS

Classical anthropometric methods have not provided the appropriate information base for designing the next generation of long-duration spacecraft because:

1. Data are obtained in fixed or "posed" positions that are not specific enough to the typical interfaces between the crew and work space, living space, and personal and special equipment. For example, the anthropometric eye-level height for a "posed" sitting position is 31.32 in., while the functional operational height is 29.66 in. (King, 1952). The difference of 1.66 in. can be critical for both performance and comfort. Another study for a specific piece of equipment showed a correlation of 0.68 between a posed sitting acromial height (the anthropometric standard) and functional shoulder height that the individual actually assumed when using the equipment (Jantz and Ellis, 1967).
2. Data generally are not specific to the environment in which man

operates in space. A comparison of activities performed under weightlessness and terrestrial conditions has pointed to the need for "spatial anthropometrics" where not only the functional tasks are considered but the influence of 0 or partial *g* on man's body dimensions and physical performance are considered. For example, what are the typical body positions assumed under weightlessness, and what are the anthropometrics of these positions? What are the paths of movement for the body and its members when gravity need not be overcome? Do changes in the structure of motion affect the way tasks should be designed in terms of forces and the biodynamics of movement?

Spatial anthropometric data are needed that are tailored to typical functions performed in the space environment if adequate performance and comfort is to be assured for long-duration flight. The implementation of such a program requires research in orbital vehicles probably using photogrammetric techniques complemented by ground-based simulations to extend the population data base. Ground-based data also must be validated empirically with flight data. Particular attention should be given to the use of free space and the characteristic postures the individual assumes for representative tasks. The relationship to work spaces, "chairs," "beds," bathing compartments, hatches, tunnels, and other elements of the system must also be considered.

While the most important research needs relate to spatial anthropometry, other investigations might consider ethnic factors related to multiracial, multination crews; age as related to both the long training periods and the long flights; sex differences for mixed crews; and occupational differences for mixed crews of scientists, pilots, and technicians.

RECOMMENDATIONS

1. The design of the spacecraft for long-duration missions should incorporate from the beginning the human-factors requirements necessary for life support and safety, optimal habitability and comfort, and operational efficiency. Broad research programs, requiring close coordination between the aerospace engineer and the human-factors expert or bioengineer, will be necessary to identify and accommodate the many elements involved.

2. Because of individual differences even among highly selected, homogeneous astronaut pools and the probability of greater differences among the more heterogeneous pools of scientist-astronauts and possible foreign collaborators, a philosophy and policy should be established on whether long-duration missions will require tailor-made provisions for each crew member or whether standard, but adjustable, dimensions can be tolerated. Interchange of crew members' roles during flight because of exigencies and possible last-minute interchange between flight crew and backup crew suggest that the matching of physical factors with human-factors needs will be better accommodated by standardized, adjustable provisions rather than tailor-made, individualized provisions.

3. In view of the greater heterogeneity of crew members likely on missions of long duration, anthropometric design data should be obtained from appropriate but correspondingly broader and more heterogeneous samples.

4. In establishing physical and human-factors criteria for spacecraft design, "space anthropometrics"—dynamically determined and functionally oriented dimensions—should replace insofar as possible the traditional static physical anthropometrics.

4 Sensory, Perceptual, and Motor Factors

The astronaut's ability to make accurate sensory and perceptual discriminations of his environment, both inside and outside the vehicle, and the timeliness and accuracy of his responses to specific stimuli, bear critically on the success of spaceflights. In a mission of long duration the astronaut will be required to make appropriate responses to stimuli day after day and month after month. For example, he must faithfully detect and discriminate the onset and offset of visual, auditory, and other types of stimulus without error and delay and respond appropriately by checking readout displays, flipping switches, pulling and pushing levers, manipulating tracking controls, and performing other such tasks. Because of the central importance of sensory, perceptual, and motor processes in long-duration spaceflight, every effort must be made to anticipate the qualitative and quantitative changes that may occur in these processes during the course of such missions. Accordingly, identification of the types of change that might occur, however small the probability or magnitude of change, is a significant first step.

With this goal in mind, a comprehensive survey was made of the

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relevant scientific literature. Because the environmental characteristics expected to have most influence here are relative confinement and isolation, reduction and restriction of sensory and perceptual stimuli, and monotony, emphasis was placed on studies dealing with the effects of confinement, isolation, sensory and perceptual deprivation, and other types of stressor on sensory and perceptual processes and on perceptual-motor performance. Initial survey disclosed two extensive bibliographies (Weinstein *et al.*, 1968; Zubek, 1969b), which were relied upon heavily in preparing this review. Important secondary sources included *Sensory Deprivation: Fifteen Years of Research* edited by Zubek (1969b), *Sensory Restriction* by Shultz (1965); and *Sensory Deprivation* edited by Solomon *et al.* (1961). The studies reported in this survey were selected on the basis of relevance; virtually all concern effects of confinement and isolation as these factors seem far more apposite to the situation at hand than do other stresses. No studies dealing with long-term periods (i.e., months or years) of confinement and isolation were encountered. Most studies wherein the individual has been severely deprived of sensory or perceptual input have dealt with durations of less than one week. A few have lasted for one to two weeks; virtually no published studies have extended beyond two weeks. Several 30- to 90-day studies have recently been completed, e.g., Sealab I and II, the Gulf Stream Drift Mission, McDonnell Douglas I and II, Tektite I and II (*cf.*, Del Vecchio *et al.*, 1970; Haigh, 1971; Helmreich, 1971; Pauli and Cole, 1970; Pearson and Grana, 1971; Radloff and Helmreich, 1968), but results available at the time of this writing (January 1970) were not applicable to this topic. It is not certain that all relevant variables were taken into consideration in these studies, but even so, they may have been closer simulations of the spacecraft environment than laboratory experiments on sensory deprivation have provided. A long-duration Russian study (one year in a capsule, three men) has been reported to have had serious psychological aftereffects on its occupants, but details are not available. In any event, no published studies, with or without severe sensory or perceptual deprivation, have entailed durations of confinement and isolation even approaching those required for planetary missions. On the other hand, Suedfeld (1968) has argued that the more severe restrictions imposed in laboratory studies of sensory and perceptual deprivation, although of shorter duration, may accelerate changes in behavior of the types that might eventually occur on long missions. It seems reasonable to suppose that an astronaut's interactions with the same individuals and physical environment day after day, and the prolonged restriction of movement imposed by the space vehicle, could ultimately lead to changes in behavior similar to those reported in relatively short-term deprivation studies despite the fact that the environment of a space capsule may involve boredom from repetition of stimulation more than sensory deprivation *per se.* Although the experimental data are rather sparse and often contradictory, the total body of information from such studies at least provides a basis for educated guesses concerning the types of perceptual and motor changes that one might anticipate during long-duration missions.

Most of the studies summarized below not only involved social isolation and physical confinement of the subjects but subjected them to varying degrees of sensory and perceptual deprivation. The term "sensory deprivation" typically has been employed to designate an absence of, or a marked attenuation of, sensory input to one or more modalities, usually visual, auditory, or tactual. The term "perceptual deprivation" has been used to designate a reduction in patterned, intermittent stimulation in one or more modalities. For example, subjects may be exposed continuously to diffuse light and "white noise" but not to patterned or figural stimulation. This review is organized in terms of the dependent or response variables concerned, i.e., in terms of sensory, perceptual, and perceptual-motor discriminations or response processes. In the discussion that follows, the first section is concerned with *sensory and perceptual phenomena* and contains the following major subdivisions: vision, audition, minor senses, and time perception. The second section deals with *perceptual-motor performance,* including tasks requiring quick reaction, simple tasks requiring both speed and accuracy, and complex tasks requiring a high degree of neuromuscular control. The third section provides a *theoretical base for interpreting the effects* of isolation and confinement on perceptual and motor processes. The last section discusses the *implications of the findings* for long missions and raises questions that may need consideration in the planning of such missions.

SENSORY AND PERCEPTUAL PROCESSES

VISUAL FUNCTIONING

Brightness Very little information is available on the effects of isolation and confinement on brightness phenomena. Most studies encountered in the literature reported information on absolute brightness thresholds, but few dealt with brightness discrimination.

Generally speaking, brightness phenomena seem to be unaffected in studies designed to produce a state of sensory or perceptual deprivation. Zubek and Wilgosh (1963) and Zubek (1964a) found no significant change in ability to match the brightness of two lights after seven days in an isolation chamber under conditions of unpatterned light and white noise. After 14 days of isolation in the same environment, Zubek (1964b) found no significant changes in critical flicker-fusion frequency (c.f.f.). In one of the pioneer studies at McGill University (Doane *et al.*, 1959), no change was found in c.f.f. after four days of social isolation and perceptual deprivation. In contrast with these negative results, Nagatsuka (1965) reported a decrement in brightness discrimination, as measured by the c.f.f., after only two days of perceptual deprivation. In this same laboratory (Nagatsuka and Maruyama, 1963), it was found that electrical flicker-fusion frequency decreased after two days of isolation. This phenomenon appears highly similar to c.f.f., the primary difference being that subjective light flashes (phosphenes) are generated by presenting rectangular voltage pulses across the eyes. Just why the Japanese investigators obtained detrimental effects in brightness discrimination after only two days of isolation, whereas Zubek and associates obtained none after as much as 14 days of isolation, is not clear. The studies by Zubek and associates were methodologically sound, and we conclude that the evidence strongly favors the view that severe and relatively prolonged sensory and perceptual deprivation has little or no effect on the ability to make brightness discriminations. If a detriment does in fact occur after two days of isolation, it apparently is a temporary phenomenon which dissipates with continued isolation (Zubek, 1969b, p. 214).

Color Perception In contrast with the apparent lack of effect of social isolation, confinement, and sensory or perceptual deprivation on brightness discrimination, several studies have reported changes in color discrimination. In the early McGill University work (Bexton *et al.*, 1954; Doane *et al.*, 1959; Heron *et al.*, 1956), subjects almost universally reported qualitative changes in their color perception following release from isolation and perceptual deprivation. Colors appeared brighter and more highly saturated. These qualitative changes have been confirmed by Zubek *et al.* (1961) and others.

Despite the dramatic qualitative changes reported, which might suggest an increase in color sensitivity, systematic investigation of quantitative changes in color discrimination suggests an impairment effect. Doane *et al.* (1959) first noted some deterioration on a yellow color-matching test before and after three days of perceptual deprivation. In a more thorough study, Vernon *et al.* (1959, 1961a) observed significant deterioration in ability to identify accurately figures from the Dvorine Color Test after two to three days of social isolation and perceptual deprivation.

Some of the most definitive work reflecting adverse effects of isolation and perceptual deprivation on color discrimination has been done by Zubek and his colleagues. After seven days of social isolation and severe perceptual deprivation in which subjects lay on their backs in an enclosed chamber, wore translucent goggles, and listened to white noise, Zubek *et al.* (1962) found color discrimination, as measured by the Farnsworth-Munsell 100-Hue Test, to be markedly impaired. The preisolation and postisolation difference scores derived from the color discrimination test differed significantly between the deprived subjects and two different control groups, one of which was totally unconfined and the other of which lay on pads for a week but without social and perceptual deprivation. Subsequent studies have shown that the detrimental effect can be produced by severely immobilizing subjects who are neither socially isolated nor deprived of normal vision and auditory stimulation. Subjects strapped inside a coffin-like box for 24 h (Zubek *et al.*, 1963) or one week (Zubek and MacNeill, 1966) yielded preimmobilization and postimmobilization difference scores on the Farnsworth-Munsell Test that differed significantly from controls who either (a) lay in a supine position but without constraint or (b) were totally unconfined.

The detrimental effects reported above disappeared within an hour or two after the subject had been released from the deprivation situation. However, the consistency of these findings under a rather wide variety of deprivation conditions suggests that the possibility of changes in color perception during a prolonged space mission should not be ignored. The findings also give credence to the introspective reports of Siffre (1964), who, after living alone in darkness in an underground cavern for over two months, reported considerable difficulty in making color discriminations, particularly between greens and blues, and tended to confuse the two for more than a month after leaving the cavern. His report, coupled with the experimental findings reported above, suggests that prolonged and severe deprivation, whether it be visual, auditory, or kinesthetic, may lead to color discrimination impairment from which recovery tends to be slow.

Depth Perception and Size Constancy The early McGill University studies of sensory and perceptual deprivation reported qualitative changes in the physical environment following confinement, which strongly suggested impairment in depth perception. It was stated, for example, that the environment looked two-dimensional: objects did not stand out from the background (Bexton *et al.*, 1954), and the walls sometimes seemed to sway toward and away from the subject (Heron *et al.*, 1956). In one of the later McGill studies (Doane *et al.*, 1959), it was reported that depth perception deteriorated in some subjects but tended to improve in others, also that size constancy was significantly impaired. Later studies, many of which have employed more severe deprivation conditions, have failed to show any significant changes in depth perception or size constancy (Vernon *et al.*, 1959, 1961a; Freedman and Greenblatt, 1960; Freedman *et al.*, 1961; Schwitzgebel, 1962; and Zubek *et al.*, 1961, 1962, 1963a, 1964a, 1964b, 1966). Zubek (1964b) failed to detect any significant changes in depth perception and in size constancy after 14 days of perceptual deprivation, the longest deprivation period employed in any of these studies.

Very recently, Zubek *et al.* (1969a) obtained a significant decrement in depth perception and size constancy after one week of the most severe kind of deprivation. Thirty male subjects (university students) were placed individually in coffin-like boxes padded with foam rubber. The head rested in a padded head holder, the feet in V-shaped restraining holders. The arms, legs, and trunk were strapped to the base of the box firmly but not so tightly as to interfere with circulation. While the straps were removed at specified times, e.g., for nine hours during the night and during mealtime, the subject was immobilized during virtually all his waking hours. In addition to this severe immobilization, he wore a translucent face mask which transmitted only diffuse light, and he was exposed continuously to white noise. Social interaction with the experimenter was kept to an absolute minimum. Twelve of the 30 subjects were able to remain in this extremely impoverished physical and social environment for the specified period of one week. The preconfinement and postconfinement difference scores of these 12 were found to be significantly different from (a) a control group that had remained similarly immobilized for a week but without visual, auditory, or social deprivation and (b) a control group that had remained in the "coffin" for one week but without restraint or lack of visual, auditory, and social stimulation.

Thus it was shown that under the most extreme conditions of perceptual deprivation and social confinement a decrement in depth perception or size constancy can occur. The finding is supported by a rat experiment in which Walk *et al.* (1965) demonstrated that if animals are kept in darkness from birth for a long enough time (approximately five months), they do not discriminate depth as measured with a visual cliff apparatus. Results obtained from men working in an extremely homogeneous visual environment deficient in texture, figure-ground, and the like, also are consistent with these findings. Smith (1966) reported that men working in Antarctica experienced "white-outs"; they also tended to overestimate the size of objects and to underestimate their distance.

Since changes in depth perception and size constancy have been demonstrated to occur only under the most extreme conditions of sensory deprivation, social isolation, confinement, and physical visual environments resembling a Ganzfeld (uniform and homogeneous field), it seems rather unlikely that any important change will occur in these perceptual processes during a prolonged space mission because such degrees of sensory deprivation will not exist. As a precautionary measure, however, these processes should be studied in future experiments related to long-duration mission planning.

Form Perception A number of isolation and confinement studies have investigated visual phenomena pertaining to the perception of form, but few carefully designed studies have dealt with the topic. Results reported in the literature tend to be inconclusive and inconsistent, leaving a feeling of uncertainty as to whether there are any effects of prolonged sensory deprivation and confinement, and if so, what might be the nature of the effects.

The qualitative reports of the initial McGill experiments (Bexton *et al.*, 1954; Heron *et al.*, 1956; Doane *et al.*, 1959; Heron, 1961) indicated that the effects of perceptual deprivation, social isolation, and confinement on form perception may be rather extensive. After two to four days of isolation, subjects stated that they had difficulty focusing and that objects appeared fuzzy; shapes were distorted, plane surfaces appeared warped, concave, or convex; straight lines appeared curved; and human faces were distorted. Based on these qualitative statements one might anticipate a relatively easy demonstration of quantitative changes in form perception before and after confinement, but such is not the case. For the most part, only those studies dealing with measures that are subject to experimenter bias during scoring have yielded positive results. For example, Freedman and associates (1960, 1961) found a difference in the quality of the reproduction of simple forms (straight lines, crosses, triangles, and arrowheads) between a control group and a group subjected to 8 h of sensory deprivation. These same investigators, together with a group of Japanese experimenters (Hariu and Ueno, 1964; Ueno and Tada, 1965a, 1965b), found a decrement in the ability of sensory-deprived and socially isolated groups, as compared with nonisolated controls, to reproduce Bender-Gestalt figures. Because scoring the quality or accuracy of figures reproduced freehand with paper and pencil clearly requires experimenter judgment, it is quite possible that the results reported in these studies may have been inadvertently affected by experimenter bias.

In any case, other studies do not show the clear-cut effects reported in the above work. Zubek *et al.* (1961) looked for the kinds of perceptual distortions reported by the McGill investigators after having subjected 16 individuals to perceptual deprivation and social isolation for 7 to 10 days and found only extremely minor changes. In a 24-h immobilization study, Zubek *et al.* (1963a) observed no deterioration in the ability of 34 of 40 subjects to reproduce the simple forms employed by Freedman *et al.* (1960, 1961). Three subjects reported slight distortions in the shape and size of arrowheads.

Simulated flights of various kinds have failed to reveal any marked impairment in form perception. Air Force officers confined for 48-h periods in a mockup aircraft escape capsule with normal sensory input showed no decrement in the performance of tasks requiring fine form discrimination (Ormiston and Finkelstein, 1961). Patton and Randle (1963) found no appreciable change in the ability of two subjects confined for 7 days in a two-man space capsule to make complex pattern discriminations. Chiles *et al.* (1968) observed no decrement in the ability of two- to four-man crews on simulated 15- to 30-day missions to perform tasks requiring fine form discrimination.

Due to the inconsistencies in the literature, the effects of isolation and confinement on form perception cannot be assessed with confidence at the present time. Frequently reported insignificant findings favor the conclusion that the effects are minimal, but more and better research is needed to provide a definitive answer.

Movement Perception Some of the most striking effects of perceptual deprivation, isolation, and confinement, as reported in early studies (Heron *et al.*, 1956; Doane *et al.*, 1959; Heron, 1961), related to perceived movement. Many subjects reported that, even when their heads and eyes were fixed, objects in the physical environment seemed to drift about and contract or expand in size, and the surfaces of objects seemed to shimmer or undulate. Subjects also said that when they moved their heads or eyes, objects in the physical environment seemed to move. One subject reported that a slowly rotating straight black line appeared S-shaped, the ends of the line lagging behind the center (Heron *et al.,* 1956). These interesting qualitative reports have led to a number of studies concerned with assessing the quantitative changes in the perception of apparent movement as a result of sensory and perceptual deprivation, isolation, and confinement.

Several attempts have been made to replicate the S-shaped phenomenon, termed "perceptual lag," observed by the McGill subject. Freedman and Greenblatt (1960) failed to replicate this phenomenon in subjects in 8 h of perceptual deprivation, but they did note a significant reduction in the apparent angular speed of the rotating line. Pollard *et al.* (1963) likewise report a reduction in the apparent speed of a moving line observed by subjects after 8 h of perceptual deprivation. Freedman and Held (1960) and Held and White (1959) have observed an underestimation of the speed of rotation of a hand after as little as 30 min of perceptual deprivation. The results of these studies suggest that while the perceptual lag phenomenon reported by the McGill subject was a transitory, illusory event, the apparent speed of movement of objects does in fact decrease after a rather short period of perceptual deprivation. However, one would expect that the interruption of patterned visual input is primarily responsible for this phenomenon, and that social isolation and confinement have little to do with it.

With respect to apparent movement (autokinetic effect and phi phenomenon), the McGill group observed no change in latency of onset of the autokinetic effect or in the time interval required to elicit phi movement before and after three days of perceptual deprivation and social isolation (Doane *et al.,* 1959). Walters *et al.* (1963) also failed to observe a change in latency in the onset of autokinetic movement before and after penitentiary inmates were socially isolated for four days. However, Zubek (1964a) and Zubek and Wilgosh (1963) showed that after seven days of perceptual deprivation and social isolation, the latency of onset of autokinetic movement doubled. No similar decrement in the phi-phenomenon threshold has been clearly demonstrated, although Nagatsuka and Maruyama (1963) did report an increase in threshold of apparent movement after two days of perceptual deprivation. Based on these studies, it is questionable whether autokinetic and phi movement are impaired by the disruption of patterned visual input. Assuming that such disruption does slightly alter the perception of apparent movement, whether it be autokinetic or phi, it seems highly improbable that this will be a significant variable in long-duration space missions.

Other Visual Perceptual Phenomena One or more studies have reported information on the effects of perceptual deprivation, social isolation, and confinement on visual afterimages, figure-ground reversal, the Muller-Lyer illusion, identification of Gottschaldt embedded figures, and spatial orientation. Doane *et al.* (1959) stated that both positive and negative afterimages were more pronounced in 13 subjects who remained in perceptual deprivation for four days, but apparently few attempts, if any, have been made by other investigators to replicate their observation. This should be done.

Conflicting results have been obtained with respect to the Muller-Lyer illusion. Freedman and Greenblatt (1960) reported no effect of 8 h of perceptual deprivation on the average extent of the illusion, but Freedman *et al.* (1961) claimed that the variability of the individual alignments was significantly greater for the experimental than for the control subjects. In contrast with Freedman and Greenblatt's finding of no change in average extent of the illusion, Ueno and Tada (1965b) obtained an increase in average magnitude.

Reports on figure-ground reversals are equally contradictory. Doane *et al.* (1959) and Freedman and Greenblatt (1960) found no effect of isolation and perceptual deprivation on number of reversals. Freedman *et al.* (1961) later reported that perceptually deprived subjects made more reversals of both the stair steps and face vase illusions per unit time than did control subjects. In later studies, Zubek and associates (1962, 1963a, 1966) have consistently obtained fewer reversals from subjects who are perceptually deprived, severely immobilized, or both than from controls.

Results obtained with Gottschaldt embedded figures are equally inconsistent. One study (Scott *et al.*, 1959) has reported that after four days of perceptual deprivation the ability to locate embedded figures is adversely affected; another (Ormiston and Finkelstein,

1961) found no appreciable change during two days of confinement; and a third (Schwitzgebel, 1962) found no significant change after 8 h of perceptual deprivation.

The final study to be mentioned here is that of Heron (1961), who reported serious impairment in the ability to follow verbal spatial directions (e.g., take two steps forward, turn right 90°, take three steps, turn right 90°, then return to starting point).

In view of the sparsity and inconsistency of information on the perceptual phenomena mentioned here, it is impossible to conclude from such studies whether these phenomena will occur under the conditions of long-duration space missions. Even if one or more of them were to be affected, it seems unlikely that changes in any of them, which for the most part are perceptual epiphenomena that we normally ignore in our environment, would significantly affect an operator's performance, unless like other symptoms, real or imagined, they began to worry him.

Visual Imagery and Hallucinations The reports of the strange visual sensations experienced by subjects in the original isolation experiments conducted at McGill (Bexton *et al.,* 1954; Heron *et al.,* 1956; Heron, 1961) stimulated much interest in the investigation of visual imagery and hallucinatory activity. Zuckerman has written a recent excellent review of this work (1969a). (See also Chapter 7, section titled Factors Encouraging Subjective Experience.)

The literature is frequently contradictory, with some investigators reporting hallucinations and vivid imagery in subjects, some subjects even mistaking their images for reality (Heron, 1961), while others do not find even one subject reporting visual sensations (Vernon *et al.,* 1961a). This is not surprising in view of the great variety of environmentally manipulated independent variables, which seems to be nearly matched by the large number of dependent variables. Moreover, there are great varieties of incidental situational factors which may or may not be critical in the experimental situation, although these are seldom subjected to experimental investigation. The literature as a whole, however, provides rather convincing evidence that perceptual deprivation, social isolation, and confinement are conducive in varying degrees to evoking visual imagery and hallucinatory activity. The frequency with which imagery and hallucinations are reported by sensory-deprived subjects clearly is related to (a) the nature of the instructions or comments made to them prior to, during, and after confinement; (b) the set or expectancy of the subject; (c) the frequency or degree of opportunity for the subject to report his experiences; and (d) the background and motivation of the subjects as well as the circumstances under which they perform. In the McGill studies wherein subjects were encouraged to report their novel and unexpected visual sensations, a high incidence of hallucinatory-like experiences were reported. On the other hand, Zubek and associates (1961, 1964a, 1964b) obtained a very low incidence of such reports when subjects were required to wait until the end of the experiment before reporting. The role of set and expectancy has been elucidated in studies by Murphy *et al.* (1963), Jackson and Kelly (1962), Pollard *et al.* (1963), and Zuckerman and Cohen (1964), among others. The power and importance of suggestion should not be underestimated; countermeasures in the form of education and discussions should be considered.

The types of sensation reported range from "seeing" unstructured and uninterpreted blobs of light to visualizing highly meaningful and animated objects and events. Zuckerman and Cohen (1964) have grouped the reported events into two general categories: (a) those that are relatively simple and lacking in meaning, including uninterpreted diffuse light, diffuse forms interpreted as clouds or smoke, and recognizable geometric forms and (b) those that are complex, meaningful, and animated, such as seeing "a procession of squirrels with sacks over their shoulders marching purposefully" (Bexton *et al.*, 1954).

The incidence of reported visual imagery and hallucinatory activity, including those confinement studies in which the subject was neither socially isolated nor deprived of patterned visual stimuli (Wexler *et al.*, 1958; Solomon and Mendelson, 1962; Davis *et al.*, 1960, 1961), makes this subjective phenomenon deserving of attention in future data-gathering projects related to long-range space missions. If hallucinations should occur during the performance of crucial jobs in space, the consequences might be serious. On the other hand, highly motivated and disciplined veterans under conditions of spaceflight and with important tasks to perform, may well be less subject to hallucinatory experiences.

AUDITORY FUNCTIONING

In comparison with the considerable data available on the effects of sensory restriction, isolation, and confinement on visual functioning, relatively few data are available on auditory functioning. For one thing, it is more difficult to isolate a subject from sound stimulation since there are always physiological sources such as breathing, coughing, and other internally generated noises.

Difference Thresholds Auditory difference thresholds for pitch have been obtained in three studies varying in duration and nature of sensory restriction. No significant changes were found in the ability to discriminate pitch after seven days of sensory deprivation (Zubek *et al.*, 1961), 18 h of perceptual deprivation (Suzuki *et al.*, 1965), and 1 h of auditory and visual–auditory perceptual deprivation (Batten, 1961). In relation to intensity discrimination, Zubek *et al.* (1961) reported no significant changes after seven days of sensory deprivation. In a later study, not only did Duda and Zubek (1965) demonstrate that there was no impairment, but they presented data showing an increase in ability to discriminate intensity differences. They found a significant increase in auditory flutter-fusion frequency, a measure related to both intensity and temporal discrimination, after seven days of visual sensory deprivation.

Absolute Thresholds The data are less clear relative to the effects of sensory restriction on absolute auditory threshold. Auditory threshold did not change significantly as a function of sensory restriction in three differing situations: seven days of sensory deprivation (Johnson *et al.*, 1968), seven days of visual sensory deprivation (Duda and Zubek, 1965), and 18 h of perceptual deprivation (Suzuki *et al.*, 1965). Two additional studies indicate that sensory restriction significantly influences absolute auditory threshold but in conflicting directions. Krylov (1965) found that auditory threshold decreased during a 27- to 30-day period of perceptual deprivations (including constant noise of about 60 dB). The greatest decreases in threshold were noted on the first and last days of restriction. These data are difficult to interpret since appropriate control data were not given. Contrarily, Katz (1965) reported a temporary decrease in auditory sensitivity in one ear after it was plugged for 15 h. These data also are difficult to interpret, because auditory threshold was not determined for the unplugged ear. These results might be explained by a shift in attention to stimulation of the unplugged ear, which would raise the threshold of the plugged ear.

In conclusion, sensory restriction appears to have little detrimental effect on auditory functioning as measured by absolute and difference thresholds. Data reported on difference thresholds were consistent in this regard. The data were more variable in respect to absolute threshold. The majority of studies indicate that absolute auditory threshold remains unchanged during sensory restriction. The studies indicating a change are difficult to interpret due to lack of appropriate controls.

CUTANEOUS FUNCTIONING

Cutaneous functioning appears to be particularly affected by sensory restriction, isolation, and confinement. Changes have been noted in tactual and pain sensitivity and, to a lesser degree, in heat sensitivity.

Tactual Acuity Three measures have been used to assess the effects of sensory restriction on tactual functioning: tactual fusion frequency of critical percussion frequency, two-point threshold, and electrical cutaneous flicker. Shewchuk and Zubek (1960) developed the tactual fusion-frequency technique, which consists of increasing the frequency of an interrupted airjet until the subject reports a continuous sensation. Although this method involves both touch and temporal discrimination, it gives measures of tactual acuity which correspond closely with those given by the two-point threshold method (Shewchuk and Zubek, 1960). Zubek (1964a) found that seven days of perceptual deprivation with no intrusions resulted in an increase in tactual fusion frequency measured from the forearm and index finger. More detailed investigation of this phenomenon in studies employing seven days of limited restriction indicated that tactual sensory deprivation (isolation of a circumscribed area of the skin, e.g., the forearm) resulted in an increase in tactual fusion frequency, whereas tactual perceptual deprivation (constant light pressure applied to the same area of the skin) resulted in a decrease in tactual fusion frequency (Aftanas and Zubek, 1963a, 1963b, 1964). Similar changes in tactual fusion frequency were obtained in a homologous area of the contralateral forearm, which suggested that these effects were of central origin (Aftanas and Zubek, 1964). Increased tactual acuity also was obtained as a result of single modality restriction in modalities other than touch. Seven days of visual sensory deprivation (Zubek *et al.*, 1964a) and visual perceptual deprivation (Zubek *et al.*, 1964b) resulted in an increase in tactual fusion frequency.

Studies using the traditional two-point threshold measures of tactual acuity corroborate the above results. Both these measures were obtained in the seven-day tactual sensory and perceptual deprivation study by Aftanas and Zubek (1964), and both measures indicated that tactual sensory deprivation resulted in increased sensitivity, and that tactual perceptual deprivation resulted in decreased sensitivity. A number of studies have demonstrated that two to three days of perceptual deprivation results in a decrease in two-point threshold (Doane *et al.*, 1959; Nagatsuka and Maruyama, 1963; Nagatsuka and Suzuki, 1964).

Nagatsuka and Maruyama (1963) found that the effects of two days of perceptual deprivation on "electrical flicker" indicated decreased tactual sensitivity. (The electrical flicker technique consists of stimulating the cornea of the eyes with a rectangular 20-Hz pulse. The threshold for flicker sensation is determined by increasing and decreasing the intensity of the electrical stimulation in a manner similar to the psychophysical method of limits.) This is a measure of tactual sensitivity (absolute threshold) rather than tactual acuity, which may account for the apparent inconsistency between these results, which indicate impaired tactual functioning, and the above results, which indicate enhanced tactual functioning.

In summary, sensory restriction has the following effects on tactual acuity as measured by tactual fusion frequency and the two-point threshold method: (1) tactual acuity is increased by tactual sensory deprivation (given area of the skin is isolated from stimulation), visual restriction (both sensory and perceptual deprivation), and perceptual deprivation of modalities other than touch; and (2) tactual acuity is decreased by tactual perceptual deprivation (given area of skin is stimulated with diffuse light pressure). Some evidence was offered that tactual sensitivity is decreased by perceptual deprivation as measured by "electrical flicker." The intermodality and intramodality nature of these effects suggest that they are mediated by the central nervous system.

Two factors should be mentioned in relation to the effects of sensory restriction on tactual functioning. First, these effects were obtained in studies involving relatively long periods of sensory restriction (two to seven days). Zubek (1969b, p. 230) reviewed evidence indicating that relatively short periods of restriction (2 to 8 h) have little effect on tactual acuity. Zubek *et al.* (1963a) did not find a significant change in tactual fusion frequency after 24 h of immobilization (otherwise normal conditions). This lack of effect could be due to the relatively short period of restriction or to the lack of effects of immobilization. Additional research is necessary in order to determine the minimal period of time required before changes in tactual acuity will occur. Second, the effects of sensory restriction on tactual acuity were relatively long-lasting. The duration of the aftereffect appears to be related to the magnitude of the initial effect.

Aftereffects were obtained for six days with tactual restriction (Aftanas and Zubek, 1963b); one to two days with visual sensory deprivation (Zubek *et al.*, 1964a), and less than one day with visual perceptual deprivation (Zubek *et al.*, 1964b).

Pain Sensitivity The few studies concerned with the effects of sensory restriction on sensitivity to pain have provided variable results. Vernon and McGill (1961) reported an increase in pain sensitivity (electrical shock applied to earlobe) as a result of four days of sensory deprivation. On the other hand, Zubek *et al.* (1962) reported a decrease in pain sensitivity as measured by the "time method" (applying 100–150 mcal/cm^2/sec to skin and measuring the latency of pain response) as a result of seven days of perceptual deprivation. On the basis of these two studies, it may be concluded tentatively that sensory and perceptual deprivation result in increase and decrease in pain sensitivity, respectively. Zubek (1969b, p. 232) suggested that the decreased sensitivity under perceptual deprivation may be due to the presence of white noise, which has certain analgesic properties.

Sensory restriction in the absence of white noise may or may not result in increased pain sensitivity as indicated by studies of single-modality deprivation. Visual restriction for seven days resulted in increased sensitivity for both visual sensory deprivation (Zubek *et al.*, 1964a) and visual perceptual deprivation (Zubek *et al.*, 1964b). Tactual restriction for seven days (Aftanas and Zubek, 1963a) and immobilization for one and seven days, respectively (Zubek *et al.*, (1963a; and Zubek and MacNeill, 1966), did not significantly influence pain sensitivity.

Sufficient data are not available to draw a firm conclusion about the effects of sensory restriction on pain sensitivity. In summary, pain sensitivity was increased in response to sensory deprivation and visual restriction, decreased in response to perceptual deprivation, and uninfluenced by tactual restriction and immobilization.

Heat Sensitivity The effects of sensory restriction on heat sensitivity have been investigated in three studies conducted in Zubek's laboratory. Heat sensitivity was increased by seven days of visual restriction (Zubek *et al.*, 1964a, 1964b) and was unchanged by seven days of tactual restriction (Aftanas and Zubek, 1963a). Both heat and pain sensitivity were investigated in these studies, and both were influenced in the same manner by sensory restriction. This is not surprising since both were measured with the "time method" technique under identical stimulus conditions. Heat was applied to the skin, and the subject reported when he first felt "heat" and then when he first felt "pain."

KINESTHESIS AND TACTUAL FORM DISCRIMINATION

The few studies dealing with the effects of sensory restriction, isolation, and confinement on kinesthetic sensitivity have yielded inconsistent results. These studies have employed two measures of kinesthetic acuity: weight discrimination and the estimation of angle of joint retation (bending of the arm). Weight discrimination did not change significantly as a result of seven days of confinement (Hanna and Gaito, 1960) or 18 h of perceptual deprivation (Suzuki *et al.*, 1965).

Zubek *et al.* (1963a) investigated the effects of 24 h of severe immobilization (otherwise normal conditions) on the ability of subjects to bend their arm to 20 and 60 degrees. Immobilized subjects and recumbent controls did not differ significantly in accuracy of bending, although both the groups differed significantly in their performance from ambulatory controls. In a second study performed by Zubek (1964a), seven days of perceptual deprivation did not significantly influence kinesthetic acuity in the experimental subjects as compared with ambulatory controls. If any conclusion may be drawn from these data, it would be that sensory restriction has little effect on kinesthetic sensitivity.

A decrement in performance of more complicated tasks, involving kinesthetic sensitivity and spatial orientation, has been noted as a result of sensory restriction in two studies. Doane *et al.* (1959) found that three days of perceptual deprivation resulted in impairment of the ability of subjects to follow spatial verbal directions as measured by pencil tracing or walking. These effects were statistically significant in terms of estimating direction and angular displacement. Heron (1961) reported a significant decrease in the ability of subjects to identify the shape of wire finger-type mazes after 24 h of perceptual deprivation.

CHEMICAL SENSES

Two studies have been concerned with the measurement of chemical sensitivity in relation to sensory restriction. Schutte and Zubek (1967) reported data indicating that a week of visual sensory deprivation (darkness) influenced both olfactory and gustatory sensitivity.

The olfactory recognition threshold for benzene decreased; taste thresholds to NaCl and sucrose significantly increased, but sensitivity to HCl or quinine was unaffected. In another study, sensitivity to quinine and *natrii cyclamas* (sweet) was increased after one day of perceptual deprivation (Nagatsuka, 1965). These data suggest that, as a result of sensory and perceptual deprivation, isolation, and confinement, sensitivity is increased to some olfactory and gustatory stimuli and uninfluenced by others.

TIME PERCEPTION

"Estimation of time" and "perceptual lag" are two measures most frequently used to assess the effects of sensory restriction on the perception of time. The evidence suggests that changes in time estimation are a function of the duration of restriction: sensory deprivation for 96 h (Vernon and McGill, 1963) and seven days (Zubek *et al.*, 1961) resulted in underestimation of the passage of time; perceptual deprivation for 8 h (Pollard *et al.*, 1963) and 24 h (Suzuki and Ueno, 1965) had little consistent effect on time estimation; and sensory deprivation for 4 h resulted in an overestimation of the passage of time, the degree of overestimation being negatively correlated with how long subjects stayed in isolation (Murphy *et al.*, 1962). Tentatively, it may be concluded that sensory restriction for relatively short and long periods results in overestimation and underestimation of the passage of time, respectively, and that intermediate periods have little effect. It may be noted that these effects were not evident in small groups of confined subjects: they estimated the passage of time reasonably well for periods up to two weeks (Fraser, 1968b; Thor and Crawford, 1964).

Evidence also has been offered that "perceptual lag" is increased by sensory restriction. Eight hours of perceptual deprivation resulted in an apparent decrease in speed of rotation of a moving line (Freedman and Held, 1960; Pollard *et al.*, 1963). Held and White (1959) reported this same effect after as little as one-half hour of visual, perceptual, and sensory deprivation.

PERCEPTUAL-MOTOR PERFORMANCE

Isolation and confinement laboratory studies have dealt with a wide variety of perceptual-motor tasks, which may be classified into two categories: those involving speed of reaction and those involving both speed and accuracy with emphasis on (a) perceptual discrimination, such as canceling of numbers, placing a dot in a small triangle, or making two check marks in small squares, and (b) perceptual-motor coordination, such as quality and speed of handwriting, finger dexterity, steadiness, tracing, rail walking, and rotary and light-alignment tracking. The role that vigilance plays on the performance of various perceptual-motor tasks also will be briefly considered in this section.

TASKS INVOLVING SPEED OF REACTION

Visual Only two isolation and confinement studies that measured the effects of sensory or perceptual deprivation on visual reaction time were encountered in the literature. Vernon (1963) reported that seven subjects who were sensory-deprived for four days did not differ significantly from a group of control subjects. However, eight subjects who withdrew from the experiment before the four-day deprivation period was up did significantly worse, i.e., had longer reaction times, on a simple visual reaction-time task than controls. Japanese investigators Nagatsuka and Suzuki (1964) found that subjects perceptually deprived for two days did significantly worse on both simple and choice reaction tasks than did a group of non-deprived controls. It is apparent from these studies that visual reaction time is adversely affected by fairly short periods of sensory or perceptual deprivation. However, the minimal period of deprivation would seem to be in excess of 6 h, since Leiderman (1962) observed no significant changes in either simple or choice reaction time with deprivation periods of 2 to 6 h.

Auditory Studies employing measurement of auditory reaction time have been concerned primarily with vigilance and therefore will be treated more thoroughly in the vigilance section below. Suffice it to say here that Myers *et al.* (1962, 1963b, 1966) and Smith *et al.* (1967) found reaction times of severely sensory deprived subjects to be either no different or shorter than controls depending on whether the controls were in the light or dark.

The apparently contradictory results between visual and auditory reaction time is puzzling, although the differential effects may in part be due to the presence or absence of a vigilance situation. To establish whether differential deprivation effects actually do exist for visual and auditory reaction time, research is needed in which both types of measure are obtained concomitantly from each experimental subject under identical deprivation conditions, similar care being taken to obtain both types of measure from each control subject under appropriate control conditions. The need for such research is amplified by the generally negative and contradictory findings summarized by Fraser (1968b) in relation to spaceflight.

TESTS OF SPEED AND ACCURACY

Focus on Perceptual Discrimination As with reaction time, isolation and confinement studies of speed and accuracy in which performance depends primarily on perceptual discrimination are contradictory. Zubek and Wilgosh (1963) found that persons who had been subjected to a week of isolation while wearing translucent goggles and listening to white noise did significantly worse than controls on such simple tasks as letter cancellation, placing dots in very small triangles, and making check marks in small squares. Myers *et al.* (1966) likewise found that sensory-deprived subjects did significantly worse than controls on simple tasks making up part of the MacQuarrie Test of Mechanical Skills. In contrast with these effects, Patton (1963) and Rathert *et al.* (1964) found no significant deterioration in the performance of such simple skills as letter cancellation and, in fact, reported an improvement in the latter in two men confined to a small space capsule mockup for seven days with normal sensory input. One might surmise that the impairment effects noted in the one-week deprivation studies of Zubek and Myers show up only under conditions of severe deprivation and that a longer period of isolation would be required for detrimental effects to show up in the less restricted space capsule. However, this argument is offset by later results obtained by Smith and Myers (1967) in which subjects sensory-deprived for seven days did significantly better than controls in pushing buttons and pulling a lever to terminate, respectively, a tone or noise. These latter authors think the performance enhancement may have been due to the arousing nature of the tasks. In any case, it appears that performance of simple tasks requiring discrimination of form, sound, etc., to which a subject makes a specific motor response, such as pushing a particular button or striking out a particular letter from an array, may increase, decrease, or show no change during prolonged confinement and isolation. Apparently factors other than confinement, isolation, or sensory deprivation *per se* are responsible for the observed effects.

Focus on Perceptual-Motor Coordinations A sparsity of information is available on the effects of deprivation, isolation, and confinement on simple perceptual-motor coordination tasks such as finger dexterity tests. In the early studies at McGill University (Bexton *et al.*, 1954; Scott *et al.*, 1959), it was observed that sensory-deprived subjects were slower than controls in copying a paragraph of prose, and the quality of their handwriting was poorer. Myers *et al.* (1966) also observed impairment in a copying task in sensory-deprived subjects, compared with controls. Related to these findings is Vernon's observation (1963) that hand tremor significantly increased in subjects exposed to four full days of sensory deprivation. This meager amount of data suggests that fine motor activity involving the hands and fingers may be somewhat impaired during extreme conditions of confinement and isolation. Consequently, some measure of finger or hand dexterity should perhaps be included among the perceptual-motor variables designated for further study in relation to long-duration missions.

Tracking Tasks A number of studies have looked at the effects of isolation, confinement, and deprivation on various kinds of tracking tasks, including pencil maze tracing, mirror tracing, walking a railing, rotary pursuit, and light-alignment tracking. As with the other kinds of perceptual-motor performance discussed above, there is no indication of any consistent detriment in tracking skill. If anything, there is some indication that tracking may actually improve during severe isolation and confinement.

Vernon *et al.* (1961a) found no difference in pencil maze-tracing ability between subjects sensory-deprived for 48 or 72 h and controls, nor did Walters *et al.* (1963) find any difference in degree of body sway or performance on a manual dexterity test in 40 prisoners after four days of solitary confinement. Myers *et al.* (1966) reported that sensory-deprived subjects did significantly worse than controls in a tracing task taken from the MacQuarrie Test of Mechanical Ability, but the difference was not marked. Scott *et al.* (1959) observed no difference in mirror-tracing skill between controls and subjects perceptually deprived for three days. Vernon *et al.* (1959) found that sensory-deprived subjects performed better at mirror tracing than did controls after 48 h of deprivation, but no differences existed between the two groups after 72 h.

With respect to rail-walking skill, Vernon *et al.* (1959, 1961a) reported that controls did better than experimental subjects who were sensory-deprived for 72 h. However, there was no decrement in the performance of the deprived subjects. The difference between the two groups was due to the fact that the controls improved whereas the experimentals did not. In contrast with these findings, Vernon (1963) reported in another study that seven subjects who completed four days of sensory deprivation out of an initial group of 15 did 42 percent worse after the deprivation period than at the beginning.

Studies involving performance of rotary pursuit tracking by sensory-deprived or perceptually deprived subjects have generally reported either no change or improvement. Vernon *et al.* (1959, 1961a) found that experimental subjects did significantly worse than controls after 48 h of deprivation, but after 72 h the experimental subjects were performing at about the same level of skill as the controls, their scores having drastically improved over the 48-h measures. Freedman *et al.* (1961) indicated that perceptually deprived subjects performed less well than did controls, but it is clear from their report that the deprived subjects also showed improvement after 8 h of confinement. Rathert *et al.* (1964) also reported general improvement in pursuit tracking by two subjects during the course of a seven-day confinement period; the authors attributed the improvement to practice.

A final study to be mentioned is that of Smith and Myers (1967), who subjected sensory-deprived subjects to a time-shared three-component task, one part of which involved aligning pairs of lights by manipulating a continuous control knob. The subjects' ability to perform this task concomitantly with the other two tasks progressively improved during the course of a seven-day deprivation period. Furthermore, the experimental subjects did better than a group of live-in-the-laboratory controls who were not sensory-deprived.

It seems fairly clear from the above results that isolation and confinement coupled with severe sensory and perceptual deprivation does not significantly impair tracking performance, and, in fact, the over-all picture tends to suggest that performance may be enhanced under such conditions. Smith and Myers (1967) have suggested that such enhancement in performance may be due to the hyperarousability of generally hypoaroused sensory-deprived persons when they are given something to do. The influence of arousal on performance will be discussed in more detail below.

VIGILANCE

Since the effects of isolation on vigilance are considered in another section of this report (see Chapter 5), they will be considered only briefly here. Two groups of investigators–Zubek and co-workers and

Myers and co-workers—have concentrated on the effects of sensory restriction on vigilance performance. In the Zubek studies, the visual vigilance task consisted of detecting an interruption (0.1 to 1.2 sec) in the rotation of a hand on a clocklike apparatus and the auditory vigilance task of detecting when a tone, presented once every 20 sec, was 1.24 sec in duration rather than 1 sec in duration. Subjects usually performed a visual and auditory task at the same time (vigilance or discrimination), and the tasks were administered before and after seven days of sensory restriction. A significant decrement in performance was found for visual vigilance after sensory deprivation (Zubek *et al.*, 1961) and for both visual and auditory vigilance after perceptual deprivation (Zubek *et al.*, 1962). Contrariwise, subjects immobilized for 24 h were significantly better in visual vigilance (as compared with ambulatory controls) and auditory vigilance (as compared with recumbent controls) (Zubek and MacNeill, 1966). This suggests that immobilization may enhance vigilance performance. Yet, in this same study, auditory vigilance did not differ significantly among the immobilized and ambulatory controls.

In contrast with Zubek's findings, Myers and co-workers have reported that sensory deprivation generally enhances auditory vigilance. In these studies, vigilance was measured during the course of restriction. In two studies, one consisting of three days of sensory deprivation (Myers *et al.*, 1962) and the other of four days of sensory deprivation (Smith *et al.*, 1967), the vigilance task consisted of releasing a lever when an auditory signal was detected. The latency of the response to the tone was then measured. A more traditional vigilance task was used in a third seven-day sensory deprivation study, vigilance being measured in terms of percentage of detections of an auditory signal (Johnson *et al.*, 1968). In all these studies, control subjects showed a significantly greater decrement in vigilance performance during the course of the experiment than did the sensory-deprived subjects.

In conclusion, the Zubek studies indicate that sensory and perceptual deprivation have a detrimental effect on vigilance, whereas the Myers studies indicate that sensory deprivation has a beneficial effect on vigilance. Smith *et al.* (1967) attribute this apparent contradiction to differences in task characteristics and testing procedures. In the Myers studies, subjects only had to attend to an auditory signal and performance was measured during restriction; whereas in the Zubek studies, subjects had to attend to both visual and auditory stimuli and performance was measured before and after restriction.

INTERPRETATION OF FINDINGS

One is hard-pressed for a comprehensive explanation of the rather impressive compilation of contradictory and often inconclusive findings summarized above. When looked at in terms of long-range mission planning, the findings are rather heartening, for they suggest that the effects of severe sensory or perceptual restriction, isolation, and confinement are so minor, except in a few instances, that they are difficult to demonstrate with any degree of consistency not only from one laboratory to another but often within the same laboratory.

The high incidence of nonsignificant findings that have been reported can easily be accounted for in terms of the above statement. More difficult to explain are the rather frequently reported statistically significant results obtained by different investigators but in opposite directions. The experimenters generally attribute such discrepancies to such factors as differences in the confinement situation, type of sensory or perceptual deprivation employed, population from which experimental subjects were drawn, type of control group used, duration on confinement and isolation, and the conditions under which performance is measured. Clearly any of these variables could have a differential effect on the dependent variables being measured, yet few parametric studies of such variables have been conducted. Zubek (1969b) has discussed findings in the light of the effect of such variables whenever possible.

ACTIVATION THEORY

Various attempts have been made to account theoretically for the diverse perceptual and motor changes, and other behavioral changes, that have been observed to result from isolation and confinement (Zuckerman, 1969b). One of the most popular views is in terms of activation theory or some modification thereof. Most proponents of this theory employ the notion that an inverted U-shaped relationship exists between efficiency of behavioral function and level of activation, efficiency being relatively impaired when level of activation or arousal is either too low or too high. It is impaired when activation level is too low, presumably because the organism is not sufficiently alert or attentive to detect relevant stimulus information, process it, and respond appropriately. It is impaired when activation level is too high because of a reduction in the influence of the neural inhibitory mechanisms that are involved in regulating attention and integrating and coordinating networks and pathways concerned with neuromuscular coordination and other behavioral functions. The role of the reticular formation, thalamus, and cortex in the regulation of activation and attentional processes has been described by Lindsley (1960) and others.

It has been difficult to test the activation theory experimentally, because central activation is hard to measure in human subjects. Physiological indicants must be obtained from the periphery of the body (e.g., heart rate, electroencephalogram, electromyogram, galvanic skin response, skin conductance), and unfortunately such measures sometimes do not correlate (Lacey, 1967). In recent years the visually evoked cortical response has been shown to be dramatically affected by both level of activation and direction of attention (Eason *et al.*, 1964, 1969; Donchin and Cohen, 1967; Garcia-Austt *et al.*, 1964; Haider *et al.*, 1964; Spong *et al.*, 1965; and others) and thus holds considerable promise as a sensitive and reliable index of central activation.

Stimulus-Seeking Behavior In applying activation theory concepts to explain the effects of perceptual deprivation, a number of investigators have taken the view that organisms *seek out* situations, which results in an optimal level of activation (Berlyne, 1960; Hebb and Thompson, 1954; Leuba, 1955, 1962; Schneirla, 1959). In physiological terms, if the reticular formation is either understimulated or overstimulated for a sustained period of time, the organism will seek stimulus situations that are, respectively, more or less arousing. Shultz (1965) has coined the term "sensoristasis" to conceptualize a "drive state of cortical arousal which impels the organism (in a waking state) to strive to maintain an optimal level of sensory variation." Data from a number of perceptual deprivation studies suggest that too little stimulation does in fact result in stimulus-seeking behavior (Scott *et al.*, 1959; Myers *et al.*, 1963a; Smith and Myers, 1967; Smith *et al.*, 1967). These investigators observed that experimental subjects listened to propaganda lectures or boring stock market reports more than controls after deprivation periods ranging from 6 to 150 h. Furthermore, the amount of listening by the deprived subjects increased with duration of confinement, whereas it decreased for the controls. Studies with monkeys likewise provide evidence that organisms seek stimulation when perceptually deprived. Butler (1953, 1957) and Butler and Alexander (1955) found that visually deprived monkeys learned a color-discrimination task, a lever-pressing task, and how to unlock a door in order to get a peek into the laboratory. Fox (1962), Wendt *et al.* (1963), and Lindsley *et al.* (1964) have also observed high bar-press rates in visually deprived monkeys when reinforced with light stimulation. The latter investigators interpreted the exceptionally strong and prolonged striving for light stimulation after one to three years of light deprivation as an example of "stimulus hunger" that refused to be satiated. They also thought some of the bizarre behavior manifested by the sensory-deprived monkeys was intended to create sensory self-stimulation.

Activation theory models employing the inverted U-shaped arousal–performance function also require demonstration of performance deterioration when activation level becomes too high. While there is a body of literature that gives support to this notion (Duffy, 1962), sensory deprivation studies by their very nature must focus on examination of the hypothesized inverted U-shaped relationship at the lower end of the arousal continuum.

In conclusion, the changes observed in perceptual and motor activity during perceptual deprivation, isolation, and confinement may in part be due to an imbalance in the subject's optimal level of activation. Based on the results of studies of stimulus-seeking behavior, it would appear that when activation level drops too low for comfort, the organism looks for varied stimulation in an attempt to counteract the effect. The problem of drive, activation, and attention during confinement is treated further in Chapter 5.

IMPLICATIONS FOR LONG-DURATION SPACEFLIGHTS

Making predictions about the astronaut's sensory, perceptual, and motor functions during long-range missions on the basis of results of relatively short-term isolation studies requires a degree of extrapolation that exceeds one's better scientific judgment. Yet such information provides a basis for making limited predictions and for raising questions and identifying avenues for research that might otherwise be overlooked. Had any serious impairment in sensory and motor function been observed during severe short-term confinement, such effects would certainly warrant serious consideration in long-range mission planning. As it turns out, the results of studies summarized in this paper suggest that only minimal and relatively insignificant changes in sensory and motor function are likely to occur during long-duration missions. Those sensory and perceptual processes most likely to be adversely affected are color discrimination, ability to judge distance and the size of objects, perception of the apparent speed of objects, visual imagery, hallucinatory activity, and time estimation. Those least likely to be affected would seem to be brightness discrimination and kinesthetic sensitivity. The experimental data suggest the slight possibility that sensitivity in a number of modalities, including auditory, tactual, pain, heat, taste, and smell, could be either enhanced or impaired. However, since the data are quite inconsistent as to the direction of change in sensitivity, it seems more likely that sensitivity in these modalities will be essentially unaffected.

With respect to perceptual-motor performance, there is little indication from the experimental data that reaction time or tasks requiring eye–hand coordination are likely to be adversely affected. The astronaut may in fact perform simple motor skills more accurately and efficiently under prolonged isolation than he otherwise would, simply because it gives him something to do.

SOME CONSIDERATIONS OF HYPOTHETICAL PROBLEMS

It appears unlikely that the isolation and confinement to which astronauts are subjected during long-range space missions will adversely affect their sensory, perceptual, and motor processes sufficiently to threaten seriously the success of such missions. Even so, every effort must be made to anticipate the types of situations and changes in performance that could jeopardize the mission, however remote the possibility. The speculations that follow are presented in this light and are not intended to be predictions of what is likely to happen.

Sensory Sensitivity If the effects of boredom and adaptation become sufficiently acute, the astronaut may become less sensitive or simply "tune out" old stimuli; and, because of the desire for varied stimulation, he may exhibit an increased sensitivity to new stimuli and show exaggerated orienting responses, i.e., hyperarousal and concentrated attention. Thus, when sustained attentiveness to certain "old" stimuli is crucial to the success of the mission, steps may be necessary to ensure that attention remains focused on them and that the tendency to seek out irrelevant "new" stimuli is minimized when performing crucial tasks. This, in essence, is a vigilance problem.

Perceptual Organization Sensory deprivation studies have shown impairment or distortions in the perception of color, depth, form, movement, and pattern. Visual imagery and hallucinatory activity have also been reported in these circumstances. Cases also have been reported of pilots feeling suspended or detached from the world when flying for long periods of time at high altitudes. During the long-duration mission, after months of exposure to the same limited physical environment, adverse feelings may develop toward that environment. Such feelings might result in nothing more than a perceptual-cognitive reaction that the displays, panels, and controls in the space capsule are aesthetically unattractive and boring to interact with. On the other hand, the adverse reaction could conceivably be severe enough to generate strong reactive inhibition and feelings of disgust toward the environment. Some thought should be given to ways of handling the above kinds of perceptual disorganization and potentially negative attitudes toward the space vehicle or fellow crew members given the remote possibility that any one, or some combination of them, might occur.

Perceptual-Motor Performance Due to lowered arousal, inattention, or boredom, the astronaut may: (a) respond less quickly to the onset and offset of crucial stimuli than he should; (b) increasingly tend to make errors when responding to discrete stimuli such as in selecting knobs and manipulating switches; and (c) show impairment in the smooth performance of perceptual-motor tasks (e.g., tracking) requiring a high degree of eye–hand coordination. Performance impairment also could result from hyperarousal and inattention to the task being performed, impoverished form and depth perception, breakdown in coordinated vestibulo–visual sensory input, and other factors. Such effects might be offset by monitoring the arousal and attentional state of the astronaut when in a crucial job situation (assuming the state of the art permits) and by changing his physical or physiological environment in the appropriate manner.

Suggestions for Reducing the Probability of Adverse Changes in Perceptual and Motor Processes Sensory discrimination and perceptual and motor processes are markedly affected by the motivational and emotional state of the individual. Optimal performance is most likely to occur when the basic needs and drives of the astronaut are being met. Some of these can be met easily, others only with considerable difficulty. One may suppose that the basic drives of hunger, thirst, and sleep will pose no particular problem. No doubt the quality and variety of menus contained on the flight will be extremely important.

The desire to engage in a wide variety of physical activities ("activity drive") will be more difficult to cope with. It may be necessary to develop "space" games that entail gross body movements related to walking, running, and jumping; also, games requiring fine neuromuscular control should be available. Imaginative game kits that allow the astronaut to devise original games of skill or simply to be creative might be considered.

Closely related to the activity drive is the drive for varied stimulation. Every effort should be made to provide an extremely wide variety of cognitive, intellectual, and emotional stimulation. The importance of variety has been alluded to with respect to the drives mentioned above.

Because of the taboo our society places on the sex drive and the severe restrictions imposed in the satisfaction of the drive, we may anticipate that this will be the most difficult drive for the astronaut to cope with. There is little doubt that it can be physically suppressed for months or years, but consideration must be given to the types of physiological, motivational, and emotional reactions of a maladaptive nature that may develop as a result of sexual suppression. Closely related to the sex drive is the need for love and affection. It is questionable whether radio–television contacts with loved ones on earth will totally alleviate feelings of loneliness and longings for companionship with family and friends.

RECOMMENDATIONS

1. Confinement and isolation studies with major emphasis on sensory or perceptual deprivation that have been conducted to date are too limited in duration, scope, clarity, and consistency of results to permit confident predictions of the types of changes that might occur in long-duration spaceflight. Based on the results of short-term confinement studies and the importance of such processes to mission success, the following sensory, perceptual, and motor processes should receive careful examination relative to long-duration spaceflight: perception of color, form, depth, size, movement, and complex patterns; changes in sensitivity in every major sensory modality; and changes in ability to respond quickly and accurately. These factors should be studied under conditions that provide for appropriate duration, type, and manner of confinement; size of confinement area; amount and variety of activity and environmental stimulation; and the difficulty

and complexity of the tasks to be performed. Provision should be made to control activation or arousal level so that the role of attention and vigilance may be evaluated separately from basic qualitative and quantitative changes in sensory and perceptual functions.

2. For both scientific and economic reasons, the research program should emphasize carefully planned, systematic ground-based simulations. The experimental situation should attempt to duplicate the sensory and perceptual experience, background noises, light patterns, motivating states, and the like. Furthermore, these investigations should be conducted in concert with others, as it would be inefficient to design studies to look only at sensory, perceptual, and perceptual-motor activity.

3. Although most of the basic questions posed here in relation to long-term spaceflight can be answered on the ground, those aspects of spaceflight that cannot be simulated, such as weightlessness and the combinations of stresses and goals, will, of necessity, have to be studied in orbit. It may be possible to initiate such studies in the remaining Apollo missions and in Skylab. The geometrically increasing durations planned for Skylab, though far short of the long-duration missions under study, would much enhance present predictive bases for the successful performance of astronauts on long-duration missions.

5 Motivation, Cognition, and Sleep-Work Factors; Central- and Autonomic-Nervous-System Indices

This chapter discusses possible problems for human performance in relation to three factors—motivation, cognition, and sleep. Of particular concern are possible alterations in cycles of sleeping and waking and in physiological patterns of sleep and the potential effects of such changes on vigilance, memory, problem-solving, and motivation. It is assumed that critical environmental factors such as the cabin atmosphere, food and water, and the medical and psychiatric health of the crew, will be adequately controlled.

As with other aspects of man's functioning during long-duration space missions, the relevance to spaceflight of published laboratory and simulator studies of performance and psychophysiological factors is not known. The most significant limitation is that no study even approaches the durations contemplated for long-term missions. However, some of the findings from investigations of social isolation, sensory deprivation, and sleep deprivation, from reports of wintering-over parties in the Antarctic, and from long submarine voyages point to areas of potential difficulty. [See Schultz (1965) and Zubek (1969b) for excellent summaries of the effects of sensory restriction.]

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Brownfield (1965) emphasized that the different kinds of isolation may alter the environment in four important ways. The isolated individual or group may be (1) confined to a limited space; (2) separated from highly valued persons, places, or things; (3) exposed to sharply reduced sensory stimulation; or (4) exposed to reduction in the variability and patterning of stimulation to such an extent that important aspects of stimulation may no longer be perceived. All these factors will be present to varying degrees on extended space missions, with confinement being the most constant problem. Weightlessness may potentiate difficulties of adjustment and performance.

Reports from prisoners of war, men alone at sea or in solitary confinement, and the first experimental investigations at McGill University (e.g., Bexton *et al.,* 1954) encouraged the view that sensory and perceptual deprivation are powerful methods for producing systematic alterations in cognitive processes, perception, personality, and motivation in man. However, the results in what is now a fairly extensive experimental literature have not entirely confirmed this expectation. It is clear that the performance of isolated volunteers is not always impaired. In fact, there is evidence that immediate memory span (Myers *et al.,* 1964), vigilance (Smith *et al.,* 1967), complex perceptual-motor skills (Smith and Myers, 1967), verbal learning (Vernon and Hoffman, 1956), and sensory acuity (Zubek, 1969b) may actually improve during isolation, and relatively complex mental functions have shown little, if any, systematic decline. In general, the striking alterations in perceptual organization (e.g., the bending of plane surfaces and loss of perceptual constancies) first reported by the McGill investigators have not been found in later studies. On the other hand, severe monotony is subjectively stressful. The isolated volunteer finds isolation difficult to endure, is tempted to resign from the study, and seldom offers to repeat the experience. He reports extreme boredom, restlessness, anxiety, feelings of unreality, temporal disorientation, uncertainty about the boundary of sleep and waking, and vivid visual imagery.

MOTIVATION

In a number of studies (Murphy *et al.,* 1962; Smith *et al.,* 1962; Vernon and McGill, 1960), it has been found that early subjective and behavioral responses predict tolerance for isolation. Subjects who become exceedingly bored and restless in the early stages of confinement are likely to be early dropouts from a lengthy study. Vernon and McGill found that early withdrawal could be predicted from the frequency of utilization of a viewing box in which dimly represented geometric shapes were displayed. The Antarctic studies (Gunderson, 1963; Gunderson and Nelson, 1963) as well as submarine patrols (Weybrew, 1961, 1963) indicate that monotony and boredom can be significant problems and that during periods of boredom various somatic complaints such as headaches increase in frequency. Weybrew observed that during the 83-day cruise of the USS *Triton,* motivation and morale declined after about ten days of confinement, a trend that continued throughout the voyage. Rather surprisingly, morale appeared to be higher on days such as Sunday when activities were less controlled and regimented.

Smith (1969), in his summary of the behavior of small groups in confinement, notes that several investigators have reported declining motivation throughout prolonged confinement even among initially highly motivated personnel. Such changes in morale can often be attributed to situational factors such as poor leadership, crew conflicts, task monotony, and diet, but Zubek and Welch (1963) and Zubek *et al.* (1969a) have interesting evidence for a psychophysiological correlate of low motivation. They repeatedly have found a systematic decrease in the frequency of the electroencephalographic (EEG) alpha rhythm during prolonged exposure to monotonous environments, and they report that motivational losses such as inability to study or engage in sustained purposeful activity are associated with the magnitude of this EEG change. The slowing of the EEG alpha waves persisted for as long as seven days after a 14-day exposure to unpatterned light and white noise in a confinement setting. Some subjects continued to feel apathetic, disinterested, and unable to "get started doing anything" throughout this period of slowed EEG. The state of consciousness of these subjects is not really understood. Slowing of the alpha rhythm might simply reflect a drowsy state not conducive to high levels of motivation or interest in cognitive activities. If so, it is indeed a paradox that vigilance, memory, and even complex intellectual operations are not impaired and may actually show improvement during confinement. It is possible that any new and sporadic activity, such as a test of performance, during a period of confined boredom and depression may be sufficiently arousing and rewarding to improve greatly, at least temporarily, the motivational state and the performance of the subject. Zubek's data are based on single isolated subjects; the studies should be repeated with confined groups, taking this motivational aspect of testing into consideration. This topic is discussed further in this chapter under Central- and Autonomic-Nervous-System Indices.

The mechanisms for ensuring continuing high levels of motivation including selection, leadership, group dynamics, recreation, exercise, work assignments, food, various environmental factors, and the like will be considered in other chapters of this report. Most of these factors are also important for sustaining performance in the sleep-deprived subject. In fact, the early effects of sleep deprivation (including lapses) may be due primarily to loss of motivation rather than to physiological impairment. For example, Wilkinson (1961) found that "interesting" complex tasks could be performed efficiently after a night without sleep, and feedback in the form of knowledge of results prevented decrement on lengthy continuous monitoring tasks.

Motivation for crew members should not be a problem, at least for the first long flights, and individuals who cannot tolerate long confinement will be eliminated during training. Problems of leadership and interpersonal conflict should also be apparent during training and corrected at that time. Very little is known, however, about optimal techniques for reducing monotony and boredom during long periods of group confinement. Obviously, there is a need for planning, testing, and simulating varieties of vehicle environments, task distributions, and off-duty individual and group activities.

COGNITIVE FACTORS

Although most isolated subjects report increasing difficulty with concentration, thinking, and memory, and although involvement in intellectual tasks such as reading and studying is low, measured performance has not shown consistent impairment. Smith (1969) concluded that "persons undergoing group confinement generally seem to be able to maintain their abilities, although there are some reported instances of skill decrements perhaps when cramping is severe." As noted above, studies of the intellectual functions necessary for reasoning, numerical computation, verbal learning, memory, complex perception, and communication have found no evidence of decrement for confinement periods up to one week (Zubek, 1969b; Hanna and Gaito, 1960) or two weeks (Hammes, 1964). Chiles *et al.* (1968)

found that men confined in an aircraft simulator and operating on unusual work–rest schedules could sustain optimal performance on complex tasks for as long as 30 days. Smith (1969) points out, however, that lack of control groups in most studies coupled with relatively short periods of confinement limit useful generalization from these experiments. The fact that most isolated and confined subjects feel that they have suffered impairment of intellectual functioning suggests that efficiency may be sustained at some cost to reserves and that much longer periods of confinement might cause measurable decrement. Clearly, there is a need for objective data on the performance of space-relevant tasks by well-motivated groups confined for extended periods. Skylab and subsequent missions will provide the opportunity to obtain needed data in actual flight through validation of performance on regular tasks and through preprogrammed tests.

SLEEP CHANGES

Disturbances of sleep have been an objective finding in several studies of isolated groups, and these effects increase with the duration of the isolation experience. That sleep is an area requiring attention is also demonstrated by the reports from astronauts of the longer Gemini and Apollo missions (Berry, 1970). Gunderson (1963) found that the most frequently reported symptoms during Antarctic expeditions were sleep disturbances and depression, and Mullin (1960) reported that insomnia was a widespread phenomenon during the dark, indoor, Antarctic winter season. Disruption of sleep and prolonged insomnia were attributed to cumulative tension, reduced physical activity, group suggestibility, and intense desire for stimulation. Soviet studies of isolated groups have also reported changes in sleep patterns (Lebedinsky *et al.*, 1964). The symptoms of altered sleep found in confined groups are not limited to difficulty in falling or staying asleep but may include periods of extreme drowsiness and lowered arousal similar to those found in studies of acute sleep deprivation. As in the isolation studies, sleep deprivation alters the EEG alpha rhythm, a change that is associated with specific lapses in performance on tasks that require sustained attention (Williams *et al.*, 1962).

Only one systematic study has been made of the effects of prolonged confinement on the EEG stages of sleep (Natani *et al.*, 1969). It was conducted on members of a wintering-over party at the South

Pole Station. Besides extreme social isolation for nearly nine months, the group endured a unique combination of environmental factors, including high altitude, intense cold, very low humidity, and the absence of a 24-h light-dark cycle. From sleep logs and EEG data, these investigators concluded that men on the Antarctic station averaged about 7.5 h of sleep out of 24, the range being 5.6 to 10.5 h. Despite these relatively stable (and normal) mean durations of sleep, there also existed a particularly virulent form of insomnia commonly called the "Big Eye" (Siple, 1957). The most systematic and striking change in the EEG sleep profile was a progressive decrease in the amounts of stage 3 and stage 4 (slow-wave) sleep, alterations that were not reversed for at least six months following return to the United States. The functional significance of slow-wave sleep is not known, but there are correlative studies that suggest that it is important for healthy psychophysiological functioning. For example, the altered sleep patterns found in depressive illness are characterized primarily by absence of slow-wave sleep (Mendels and Hawkins, 1967; Hawkins *et al.*, 1967). Also, subjects undergoing experimental deprivation of stage 4 sleep (Agnew *et al.*, 1967) reportedly developed the symptoms of a mild neurasthenic and depressive reaction. However, recent studies at the Navy's Medical Neuropsychiatric Research Unit in San Diego have not confirmed the latter effects. In those experiments, subjects were allowed differential recovery of EEG slow-wave or fast-wave sleep following 60 h of total sleep deprivation. No differential recuperative effects were found on either performance or neurological measures. Continuing investigation of the biological and psychological significance of the EEG stages of sleep should be encouraged.

Inflight EEG measurements in the U.S. manned program have been made only on Gemini 7 but are scheduled for the first Skylab 56-day mission. Automated onboard monitoring, recording, and analysis of EEG and EOG (electrooculographic) data, with near-real-time telemetry of results, are to be made on 21 specified nights on one crewman during regular 8-h sleep periods, with control runs preflight and postflight. Seven discrete states will be encoded: awake, four stages of sleep, rapid eye movements, and head movements. The recently developed "sleep cap," which contains the signal sensors, eliminates the need to preattach electrodes to the head: the cap is simply donned and does not interfere with the crew member. The EEG sleep measurements promise to be very valuable and should be extended to selected daytime activities as feasible.

SLEEP LOSS AND PERFORMANCE

Since progressive disturbance of sleep may be one consequence of prolonged confinement, it seems appropriate to examine possible impairments of performance as functions of sleep loss. This analysis must rely on the results of studies of acute sleep deprivation because there is very little information available on the effects of chronic sleep loss. For example, we do not know whether loss of some sleep every 24 h results in a cumulative sleep debt, nor whether sleep can be saved up ahead of time to sustain performance over a prolonged vigil.

With sleep loss, performance on certain critical tasks will eventually suffer (Johnson, 1969; Naitoh, 1969). In general, continuous, long-duration monitoring tasks, in which rate of data handling is paced by the information source rather than by the operator, are particularly sensitive to sleep loss. For example, Wilkinson (1968) found that vigilance and continuous addition tasks showed impairment if less than 3 h sleep had been obtained on the night before testing.

In their 1959 monograph, Williams, Lubin, and Goodnow proposed the lapse hypothesis to explain the impairments of performance found with sleep deprivation. Loss of sleep results in brief, intermittent lapses into deep drowsiness which increase in frequency and duration as the task and the vigil are prolonged and which are accompanied by EEG signs of light sleep. Long-lasting, work-paced monitoring, and computational and decision-making tasks that involve high information-processing requirements are particularly vulnerable to loss of sleep. There are, however, types of performance deficit with sleep loss that do not seem to result from intermittent physiological lapses. Notable among these is impairment of short-term memory. The moderately sleep-deprived subject can recall information acquired prior to sleep loss as well as a normal subject, but he has difficulty recalling the content of new messages, especially where successful performance depends on the integration of current with preceding information. Complex intellectual tasks such as problem solving and logical analysis have been resistant to sleep deprivation.

On long-duration missions it would seem that the following functions are illustrative of the tasks that the crew must be able to perform with alertness, speed, and accuracy: (1) Monitor and interpret information concerning vehicle operation, cabin, outside environment, and physiological status of personnel. These data must be communicated to earth accurately and frequently. (2) Repeatedly read values of thrust duration and direction into and from an on-board computer. (3) Recognize, interpret, and make decisions about unexpected and subtle changes in information patterns. (4) Reorient, change the course, and adjust the velocity of the vehicle. (5) Contribute to navigational data by taking accurate astronomical fixes of a complex type. (6) Trouble-shoot and repair breakdowns. (7) Perform scientific functions such as astronomical observations. Sleep loss is likely to impair the first three functions more than the last four, because the first three involve more or less continuous monitoring of displays in which critical signals demanding decisive action are rare. Thus, they resemble the vigilance tasks that have proven so sensitive to drowsy states. All operators will be superbly trained for vehicle operation, navigation, and vehicle repair, and the relatively short duration of these tasks should make them resistant to sleep loss or other adverse conditions of flight. The sensitivity of scientific tasks to drowsy states depends, of course, on the nature of the task and the degree to which data collection and analysis are automated.

The importance of specific EEG stages of sleep for the maintenance of psychophysiological efficiency is not yet understood. The early expectation that sufficient rapid-eye-movement (REM) sleep, associated with dreaming in man, would be critical for mental health has not been confirmed, and the notion that slow-wave sleep is critical for effective performance has not received general support in research to date (Webb, 1969; also, unpublished data, Navy Medical Neuropsychiatric Research Unit, San Diego). While the emphasis has usually been on effects of sleep loss, there are recent data indicating that "too much sleep" can also be detrimental to both performance and feeling state (Globus, 1969; Taub and Berger, 1969). Helping time to pass by prolonging one's usual sleep time does not appear to be the answer.

Instead of asking what kind of sleep is significant for health and efficiency, some sleep researchers are becoming concerned with the "goodness of sleep" (Monroe, 1967; Johnson *et al.*, 1970; Williams and Williams, 1966). Goodness of sleep is measured in terms of time to sleep onset, number of awakenings, number of body movements, number of changes in sleep stage, and total duration of sleep. Highly correlated with these indices of sleep are the duration and regularity of the REM–non-REM sleep cycles. In good sleepers, short periods of REM occur every 90–100 min during the night. In poor sleepers, this cycle is disrupted, and the usual orderly progression from one sleep stage to another is not present.

TECHNIQUES FOR OBTAINING ADEQUATE SLEEP

In protracted missions, the ability to get adequate sleep would appear to be crucial. What are effective techniques to ensure good sleep? There have been several approaches, varying from symbolic rituals to drugs. Careful work by Kales *et al.* (1968) indicates that use of drugs to induce sleep must be approached with extreme caution. Most hypnotics change markedly the kind of sleep a person usually gets, often lead to drug hangovers, frequently lose their effectiveness with prolonged use, and may cause severe nightmares during withdrawal. There are at present no effective hypnotics whose side effects are entirely benign, and prospective candidates for inclusion in any medical kit must be carefully evaluated.

Of increasing interest is the use of feedback methods to control many physiological variables such as heart rate, respiration, blood pressure, muscle tension, and even brain waves. It is entirely appropriate that these techniques be investigated as possible means of treating sleep-onset insomnia or, perhaps more importantly, to enable a crew member to achieve rapid onset of sleep when his usual sleep–wakefulness pattern is not possible.

Evidence that muscle relaxation can be useful in dealing with sleep onset problems has been reported by Jacobson (1938). Stoyva (1969), in a review of this area, found that autogenic training as reported by Schultz (1960) claimed 80–85 percent success with insomniacs. Stoyva has noted in his own work that deep relaxation of the head muscles is especially likely to produce strong feelings of drowsiness.

In addition to muscle relaxation, ability to control one's EEG alpha activity may be important for sleep induction. The alpha state is a relaxed condition and is generally incompatible with vivid visual imagery. Most subjects describe the alpha state as that of a blank mind. The fact that the sleep onset problems are usually associated with an inability to relax one's muscles and an inability to switch off one's thoughts suggests that a combination of muscle relaxation and alpha control might be more effective than either alone. Techniques are available that would enable study of the efficiency of either approach alone or in combination.

While self-regulation of one's internal state may not be the only approach to ensure sleep, we feel that research should be undertaken in this area. The ability to control one's internal state might also be important during periods of sustained stress, to speed the return of a state of physiological equilibrium after disruption, or to enhance periods of rest which at certain periods of the mission may be brief.

If it is impossible to ensure proper sleep, then what are the signs of sleep loss, and how can these be detected? Naitoh (1969) concludes that this is not an easy task. Increasing errors of omission or delayed reactions on monitoring tasks are a likely occurrence, but under many conditions crew members can perform relatively well on tasks that are important to their survival even after two nights without sleep. Naitoh, after examining a variety of EEG, autonomic, biochemical, and behavioral variables, concluded that the best sleep-debt indicator was the quantity of the EEG alpha waves after eye closure. Closure of the eyes is normally accompanied by the appearance of alpha waves, and their absence, relative to the individual's normal EEG, reflects the extent of the sleep debt. In cases where it is not feasible to monitor EEG activity, and for those individuals who have low or no alpha activity, some type of routine task such as addition should be available to be performed in a scheduled manner in order to provide periodic checks on the possible accumulation of sleep loss.

If unavoidable, how can the effects of cumulative sleep loss and fatigue be minimized? The lapses due to sleep loss can be reduced by physical exercise, frequent changes of jobs, immediate feedback of error, warning signals (especially auditory) when dials approach critical levels, frequent rest periods, more than one observer on a display, increasing signal-to-noise ratios, and communication from stations outside the craft. If accuracy is essential but speed is not, then transforming a work-paced task to a self-paced one by taping the data is a helpful procedure.

WORK-REST CYCLES

The question of optimal work-rest cycles has not been resolved, either in the laboratory or in the Gemini and Apollo flights. Farrell and Smith (1964) reported that in a 30-day confinement mission their subjects felt that a fixed work-rest cycle, in which some crew members slept while others worked, served as a useful reducer of interpersonal contacts and associated tensions. Obviously, such a fixed pattern of work responsibility could lead to the formation of two or more subgroups whose goals and interests might eventually conflict with over-all mission goals. Adams and Chiles (1960), Alluisi *et al.* (1963), Hartman and Cantrell (1967), and Chiles *et al.* (1968) all reported that rotating shifts which led to frequent disruption of circadian cycles were associated with irritability and some impairment of performance. Nevertheless, the data of Alluisi *et al.* (1963) suggested that with proper control of selection and motivational factors, crews could "work effectively for periods of at least two weeks and probably longer using a schedule of 4 h on duty and 2 h off." Furthermore, crews could "work even more effectively for periods of at least a month and quite probably for 2 or 3 months using a schedule of 4 h on duty and 4 h off" (p. *iii*). In general, morale remained relatively constant and high throughout the 30-day period of confinement, and irritability among crew members was confined to the early phases during which there were complaints of sleepiness and fatigue. Under routine conditions, for at least a month, performance on the 4-h-on, 2-h-off schedule was as efficient as that on the 4-h-on, 4-h-off system. However, efficiency on the former schedule was sustained only at a significant cost to reserves for meeting such challenges as acute sleep deprivation. Berry (1970) reported that astronauts have experienced difficulty in attaining good and adequate sleep in space. Various conditions contributed to this, including thruster-firing noises, communications and movement within the capsule, staggered work–sleep periods, strange and uncomfortable sleep conditions in the capsule or the lunar module, tension, and excitement. Simultaneous sleep periods seemed to work better than staggered ones.

Most studies of around-the-clock performance have found periodicities in performance functions that paralleled the circadian physiological cycle. It is well known that the circadian cycle is rather well reflected by body temperature. Depending upon an individual's daily schedule of activity, the plotting of hourly temperature readings for a 24-h period reveals a monophasic (sometimes diphasic) cycle, with maximum temperatures during the regular period of wakefulness and minimum during normal sleep hours. The most common type of daily temperature curve seems to be one that rises in the morning, falls slightly in the afternoon or evening, and reaches a low point between midnight and dawn. When a highly motivated volunteer is required to perform an exacting task demanding vigilance and judgment for 24 h (Hauty, 1959; Chiles *et al.*, 1968), the resulting performance curve looks very much like the body-temperature curve, the sharpest decline being seen during normal sleeping periods.

Despite the fact that Chiles and co-workers were able to modify this relationship by special motivational instructions, it appears that in the long run we are committed to this rhythm. It can be shifted or reversed in phase but not eliminated. Shifting or inversion of the day-night cycle is relatively easy, such shifts requiring several days to a week to achieve. The time for adaptation may be in part a function of chronological age, with younger subjects adapting more rapidly. Some physiological and behavioral circadian functions may take much longer to shift than others. Lindsley *et al.* (1964) found that the daily activity period of monkeys reared in darkness except for an hour of diffuse illumination per day tended to anchor itself to the regularly recurring light period. When the light period was shifted, the activity period did not shift immediately; it required from four to six weeks to take up its new location and stabilize there.

There is evidence that wakefulness cycles differ markedly across individuals (Kleitman and Kleitman, 1953). Some subjects wake up wide-eyed and ready to function efficiently, while others may take 3 to 4 h to reach this state. Some subjects function best in the evening hours, while others function best in the morning. Marked differences in adaptability to altered work-rest cycles have also been demonstrated: some individuals adapt rapidly to unusual cycles, while others are either unable to adapt or do so with considerable difficulty. According to Kleitman, there is a high correlation between performance efficiency and adaptability to the altered cycle as measured from physiological response systems. Hauty (1969) found that with prolonged performance, some tasks showed more decrement than others during low-temperature periods. Greatest deterioration in efficiency occurred in visual vigilance and radar reconnaissance tasks, while impairment was less marked in problem-solving and discrimination tasks.

Good experimental data are still needed to establish optimal work-rest distributions for various crew sizes. It is clear that a man's psychophysiological efficiency is normally highest at the peak of his circadian temperature cycle. However, essential data on the relative advantage of such distribution of work-sleep cycles, measured against its possible adverse effects on morale, do not exist.

A general recommendation would be that as far as is feasible crew members should maintain their usual sleep-wakefulness cycles whether this be one of 6 or 10 h of sleep. Sleep onset should be at the usual earth time. If a 24-h schedule is to be maintained, it is obviously impossible for each crew member to maintain his usual time of sleep onset, and it may be useful to adapt crew members to different circadian cycles prior to the voyage and to maintain these cycles for substantial periods in flight. As indicated earlier, the work–rest schedule will have ramifications with respect to group dynamics, to individual psychological status, and, of course, to the individual's biological rhythms. The size of the crew will also be an important factor in determining the new schedule. However, to avoid the development of isolated subgroups it would seem undesirable to have a fixed schedule for the entire mission. One suggestion for scheduling would be to have a crew member who is undergoing transition to a new shift stand watch with a member already shifted. When the new member has adapted to the new schedule, the relief can be made. If crew and competence permit such overlapping schedules then there would never be watches manned only by crew members undergoing transitions in their biological rhythms.

In selection of crews for long-duration missions, the utilization of physiological measures such as internal and surface body temperature, heart rate, electrodermal activity, peripheral and central vascular activity, as well as measures of work efficiency, should be encouraged to identify individual patterns of circadian activity and adaptability to different sleep–wakefulness cycles among astronauts. Compatibility of the crew members in these respects may well be important to the mission.

On long-duration missions, with long, quiet, and undemanding cruise phases, crew option with respect to sleep–work scheduling probably could and would be instituted. Except for emergencies and terminal points in the voyage, simultaneous sleeping of members of the crew might be permissible, and indications are that it would prove more satisfactory. Other factors such as weightlessness may lead, however, to desynchroneses of physiological rhythms, including sleep. Other things being equal, it appears that attempts should be made to maintain a diurnal sleep cycle, when possible.

CENTRAL- AND AUTONOMIC-NERVOUS-SYSTEM INDICES

In attempting to anticipate the effects of prolonged spaceflight on the central nervous system (CNS) and the autonomic nervous system (ANS), it does not appear feasible at the present time to extrapolate from existing spaceflight data. Few data are available on changes in the EEG in man during spaceflight. Similarly, aside from electrocardiograms, measures of respiration, and limited data on body temperature and blood pressure, almost no recordings of other parameters of ANS activity have been made during flight, measurements being confined to preflight and postflight physical examinations. This section thus relies heavily on studies of the effect of sensory and perceptual deprivation, isolation, and monotony on EEG and autonomic physiological measurements on the theory that prolonged spaceflight will be associated with reduction of environmental inputs. However, whether lowered gravity should be considered a reduction in sensory input or a change in sensory input has significant implications for this discussion and cannot be determined from available information.

EFFECTS OF SOCIAL ISOLATION AND PERCEPTUAL DEPRIVATION ON THE EEG

A series of studies by Zubek *et al.* (1961, 1963b; Zubek and Welch, 1963) and others (Heron, 1961; Mendelson *et al.*, 1961), have elaborated the relatively consistent observation that alpha activity of the occipital area is altered by social isolation and perceptual deprivation. The change is one of a lowering in average alpha wave frequency, with the amount of lowering related to degree and length of the deprivation experience. The longer the deprivation lasts, the lower the dominant alpha frequency falls. Recovery from such deprivation has not been so well studied. Most studies provided for only short-term follow-ups (less than one week), and recovery to resting alpha frequency was not complete in this time. Zubek *et al.* (1961) report that alpha activity returned to a basal level during a two-week follow-up, although temporal lobe theta activity was still in evidence. Zubek (1969b) suggests that the results of his earlier studies demonstrated that *perceptual isolation* produces a greater lowering of alpha frequency recorded from occipital derivations than an equal period of *sensory deprivation* (1.21 versus 0.85 cps). Incidence of theta activity, particularly as measured from temporal derivations, was equally affected by these two types of deprivation.

Lebedinsky and colleagues (quoted in Zubek, 1969b) have conducted social isolation studies for periods up to 120 days. These investigators also report lowering of alpha frequency, with the amount of lowering increasing as a function of duration of deprivation. They have reported EEG abnormalities to persist for more than 60 days after a 60-day period of social isolation. Of special interest in many of the Russian studies is the fact that subjects are not restricted with respect to movement. They live in a simulated spacecraft environment with minimal communication with the "outside world." Results of these studies are consistent with Zubek's EEG findings that both EEG abnormalities and behavioral deficits (reduced ability for sustained work, easy fatigability, changes in sleep pattern) persisted for long periods following the social isolation situation.

Less attention has been given to EEG patterns elaborated from the temporal area of the brain; the few results available suggest an increase in theta activity there. Frontal cortical sites appear not to have been investigated.

Methodologically most of the above studies have been quite primitive. EEG's have either been "eyeballed" or the frequency measured manually with a ruler.

In view of the findings that average alpha frequency is lowered under deprivation and the suggestion that this lowering is correlated with depression of cognitive efficiency, it seems surprising that more refined studies of EEG phenomena have not been conducted. Further studies should be undertaken to substantiate the relationship between cognitive efficiency and alpha frequency. Such studies could range from evaluating dominant alpha frequencies associated with drop-off in performance and errors in a continuous performance task to studies in which task presentation is contingent on the presence of specified alpha frequencies. The task should again vary in complexity from simple to complex decision-making. The studies reviewed have not attempted to assess directly the relationship between dominant alpha frequency and cognitive efficiency. They have all been correlational in nature, with time periods of sampling of EEG and measurement of cognitive efficiency occurring at different points in time. It is thus suggested that some priority be given to the conduct of studies in which these two sets of measures are evaluated concurrently.

That the alteration in cognitive performance with deprivation is not simply a function of drowsiness or lessened alertness, as might be inferred from the lowering of dominant alpha activity, is suggested by the fact that other measures of arousal suggest that subjects are in a hypervigilant state. Unfortunately, the studies in which electrodermal activity were measured did not also record EEG's. Vernon *et al.* (1961a) report decreases in skin resistance, with longer periods of deprivation (72 h) producing greater decreases than lesser periods of deprivation. Similar results are reported by Zuckerman *et al.* (1964). Not only do electrodermal measures suggest an increase in arousal, but Davis (1959), measuring muscle tension and heart rate, found both measures to be significantly increased. In the absence of data in which EEG and other physiological measures were simultaneously recorded, we would cautiously suggest that the lowering of alpha activity associated with deprivation experiences not be taken as indicative of a lowering of arousal. It is quite possible that a number of mechanisms exist for lowering dominant alpha activity and that only one of them is associated with arousal. The pharmacological literature gives adequate evidence that isomorphism between alpha desynchronization and behavioral arousal is far from perfect.

Let us assume that the relation between alpha frequency and cognitive efficiency is real and that alpha frequency might be used as a predictor of cognitive efficiency. What types of study should be conducted to investigate this phenomenon further? With current computer technology (fast Fourier transform), it is quite feasible to obtain spectral analyses of EEG's with high resolution and short processing time, thus taking the drudgery out of the analysis and allowing for much finer resolution of average alpha activity.

Other measures of alpha activity might also be proposed. Pilot studies suggest that there are marked individual differences in stability of alpha activity with respect to amplitude (or energy) and frequency. For example, spectral analyses of successive 10-sec periods of occipital EEG indicate that some subjects have extremely frequency-stable alpha generators, their dominant alpha activity remaining restricted to a very narrow frequency band. One subject showed reasonably stable and narrow-bandwidth power spectra for four successive 10-sec periods. In contrast, another subject manifested a dominant alpha frequency which was in constant flux and ranged over a broad frequency band. Assuming that there is a continuum of alpha stability with these two subjects occupying relatively extreme positions on the continuum, could one predict which subject is more likely to demonstrate alpha-slowing when placed in a deprived environment? The answer to this question can be readily determined and might lead to the development of more refined selection procedures for identifying individuals who could work most effectively in such environments.

Other questions relating deprivation phenomena to shift in alpha frequency can be asked, such as: During and following deprivation, does the entire spectrum of alpha activity shift downward, or is there selective enhancement of activity at a specific frequency? A third possibility is that the apparent downward shift of the dominant alpha frequency from nine or ten to seven or eight per second is attributable to an increase in theta activity (five to eight per second) as has been reported for the temporal area.

If cognitive efficiency is lowered during periods of low-frequency alpha production, and if procedures are available to monitor and rapidly alter such alpha activity, an alpha monitor could be developed so that (a) important decisions are only made when dominant alpha is in an acceptable frequency band, or (b) alpha activity is brought into an acceptable frequency band before the subject is called upon to make important decisions.

Severity of the deprivation experience also appears to be a variable worthy of further investigation with respect to the development of predictors of response to prolonged deprivation. To the best of our knowledge no studies have been conducted along these lines principally because most investigators have been more concerned with demonstrating deprivation-induced deficits than in developing predictors. Zubek, as well as others, has shown that the severity of EEG and behavioral deficits as well as the speed at which they evolve are a function of the intensity of the deprivation experience. The more severe the deprivation experience, the more rapidly changes evolve. At one extreme the administration of Flaxedil (which is believed to exert its major effects at peripheral neuromuscular sites) produces EEG changes with great rapidity. Van Wulfften Palthe (1962), utilizing extremely severe sensory deprivation, generated EEG changes within an hour. Zubek and Welch (1963) manipulated degree of motor restriction and found that a group not exposed to exercise and a group given exercise were differentially affected by perceptual isolation, the exercise group demonstrating significantly less EEG alpha-slowing than the no-exercise group. It would seem feasible to run studies utilizing the same subjects and manipulating degree of deprivation to determine if a predictive relationship can be generated from a knowledge of how subjects respond when shifted from a given degree of deprivation to a more severe degree of deprivation.

Finally, there are data in the literature that suggest that the speed with which alpha-slowing occurs during deprivation is also affected by "set." The literature on set suggests that the greatest degree of EEG slowing occurs during the period immediately preceding termination of the deprivation experiment. Thus Saunders and Zubek (1967) demonstrated that subjects deprived for seven days, when compared with those perceptually deprived for 14 days, demonstrated a greater decrease in alpha frequency after seven days than was true at seven days for those expecting the 14-day deprivation experience. Similar results have been reported by Lebedinsky *et al.* (1964). These results suggest that instructing subjects that they will be exposed to a seven-day period of deprivation and at the end of that period asking them (or telling them) that they are expected to stay in the chamber for an additional period of time might be one procedure to speed up the development of EEG slowing, thus reducing the time required for test periods.

SYMMETRY OF CORTICAL ACTIVITY

Recordings of EEG activity from bilaterally symmetrical skull (brain) sites demonstrate considerable individual variability with respect to symmetry of spectral plots. One such plot shows the two sides quite symmetrical with respect to distribution of EEG frequencies. Another plot, from an equally normal subject, shows quite asymmetrical frequency spectra for the two symmetrical brain sites. The questions to be raised here are: Is bilateral symmetry or asymmetry predictive of EEG and cognitive responses to deprivation? Is one side of the occipital cortex (or other cortical sites) more responsive to such experiences than the other?

The above type of analysis neglects phase information. Two recordings from a subject may produce identical or very similar spectral density plots, but one tracing may be time-delayed with respect to the second tracing; i.e., there is a phase difference between the two signals. With correlational procedures, including product–moment correlations and coherence analysis, phase information can be readily evaluated and quantified. In many subjects alpha activity is reasonably coherent, while in some it is quite incoherent. Again, one can ask questions about the relationship between coherence of alpha activity and cognitive functioning, as well as questions pertaining to changes in coherence as a function of restrictive experiences.

MEASUREMENT OF CORTICAL INTEGRITY

One further measure of EEG activity deserves to be explored with respect to its implications for the evaluation of flight candidates and crews. This technique has been extensively used by Russian investigators to evaluate "cortical tone" or "cortical excitability" and the development of "cortical fatigue" or inhibition of cortical functioning (not to be confused with their concept of "cortical inhibition"), but it has aroused little or no interest in this country. The procedure involves evaluating changes in the occipital photic driving response as a function of duration of stimulation. Russian investigators (Sokolov, 1963) claim that the frequency at which the brain can be "driven" by photic stimulation is one index of cortical excitability. The higher the frequency at which 1:1 or higher harmonic driving can be obtained, the greater the "functional integrity" of the cortex and the greater its excitability. Evidence in support of this contention is drawn from the work of Pevzner (1961) with oligophrenic (feebleminded) children, animal studies involving phylogenetic comparisons, and ontogenetic studies in man (Ellingson, 1964). Pevzner's material indicates that mentally defective children demonstrate poor photic driving, seldom attaining frequencies greater than 5 cps. Studies by Sokolov (1963) indicate that as one ascends the phylogenetic scale the frequency at which the organism demonstrates photic driving steadily increases; and Ellingson's data on newborns and infants suggests that photic driving is absent in the newborn and develops ontogenetically.

The second measure of functional integrity of the cortical "analyzer" deals with the inhibition of photic driving as a function of duration of stimulation. Using a Walter-type spectral analyzer, Sokolov reports that as a function of duration of stimulation one first sees a decrement in driving at higher harmonics of the frequency of stimulation with inhibition of driving at the frequency of stimulation evolving more slowly. Sokolov's neurophysiological interpretation of this phenomenon suggests that the effect is due to the development of "fatigue" in cortical cells, and that alteration of the driving response can be utilized as a measure of fatigability of the cortex.

ANS MEASUREMENTS DURING SOCIAL ISOLATION AND PERCEPTUAL DEPRIVATION

Autonomic measurements during isolation and deprivation have apparently been extremely limited. There are a few studies dealing with electrodermal phenomena and even fewer in which heart rate and muscle activity have been recorded. Equally unfortunate, no studies apparently have utilized autonomic and EEG recording concurrently.

The studies of autonomic activity generally show that initially subjects become drowsy and may even sleep or relax for the first few hours of the experiment. During this period, skin resistence rises, heart rate falls, and muscle tonus is decreased. After this time, there is a steady decrease in skin resistance and suggestive evidence for increases in heart rate. Measures of autonomic activity thus suggest that subjects tend to become more aroused as a function of duration of deprivation.

The results obtained in the EEG and electrodermal system are thus at variance. The EEG indicates a decrease in alertness (with perhaps concurrent deficits in performance on cognitive tasks), while an increase in alertness is measured in the electrodermal system (lowering of resting level of resistance and increase in nonspecific responses). One hypothesis to reconcile this difference is that the EEG measurements may reflect principally changes in the cerebral cortex (occipital and temporal areas), while the electrodermal changes are more sensitive to alterations in brain activity further down, perhaps at the level of the reticular formation.

Apparently, peripheral vascular activity has not been recorded in these experiments. This would seem to be an extremely important physiological measure to those concerned with cardiac decompensatory phenomena associated with long periods of exposure to 0 *g*. A number of techniques for recording such activity is available, including photoelectric plethysmography (Hertzman, 1937), strain-gauge plethysmography (Whitney, 1953), impedance plethysmography (Nyboer, 1959), and capacitance plethysmography (Figar, 1959). The last technique has special appeal because it places no mechanical or thermal restraints on the limb or body part from which one is recording. With photoelectric plethysmography, some skin warming occurs which produces compensatory responses in the peripheral vasculature. Strain-gauge plethysmography as well as capacitance plethysmography to some degree constrict the limb or phalange from which recordings are to be taken. (This appears to exert its major effect on the ability to record vasodilation responses; constriction responses are much less affected.) Whichever technique is selected, it would appear important to evaluate the effect of varying durations of weightlessness on both peripheral vascular activity (skin) and on vascular supply to muscle. Such recordings should be taken under conditions of rest, following exercise, and in response to sensory stimulation. They may well be useful in determining the amount and type of exercise astronauts should engage in during long-duration missions.

UTILIZATION OF CNS AND ANS INDICES IN CREW SELECTION AND TRAINING

A number of measurements and experiments on motivation, cognition, and sleep–work factors have been suggested in earlier sections of this chapter. The following are offered in addition.

Zubek (1964) has presented data indicating considerable individual differences with respect to decrease in EEG alpha frequency as a function of duration of deprivation and has correlated the degree of alpha slowing with impairment of performance of a variety of tasks. He interprets the impairment as being due to motivational deficits, having found a correlation of 0.67 between EEG slowing and his measure of motivational deficit. This again suggests the possible utility of using EEG recordings during experimental deprivation as a tool for the selection of astronauts who demonstrate the least amount of alpha-slowing and presumably could be counted on to maintain a higher level of task-oriented behavior than those who demonstrate greater degrees of alpha-slowing.

Should it become desirable or necessary to monitor level of alertness in astronauts, the following approach may be the most efficient. There are considerable data available in the literature that indicate marked individual differences with respect to the physiological response system that shows the greatest change as a subject passes from a state of high alertness through restful·alertness to sleep. In some subjects electrodermal measures are most sensitive to changes in alertness, while for others the EEG or cardiac measures might be most sensitive. Subjects are quite consistent or reliable with respect to the response system most sensitive to changes in state. The system in which a given crew member is most sensitive can be determined during training and the necessary instrumentation devised to monitor this system in him.

According to Zubek (1969b, p. 262), Soviet researchers report that the deleterious effects on EEG and performance produced by social isolation can be reduced by "prior exposure to isolation, performance of a special set of physical exercises, certain work-cycles, engaging in 'useful work,' and the use of an enriched vitamin diet. Unfortunately, no details are given on the types of exercises and diet that were employed." A few studies in the U.S. literature also suggest that prior deprivation experiences may serve a protective function against both EEG and behavioral deficits (Leiderman, 1962; Zubek *et al.*, 1962).

RECOMMENDATIONS

1. The long-term effects of spaceflight on cognitive functioning are clearly of first importance to mission success and cannot be predicted from existing data or theory. Ground-based experiments, and the definitive measurements in space, should emphasize evaluations of operational performance and psychological measurements (attention, vigilance, perception, memory, learning, thinking, and judgment) in conjunction with physiological measurements of the reactivity and level of the central nervous system (electroencephalogram, average evoked potentials, and contingent negative variation or slow potential shifts) and the autonomic nervous system (heart rate, blood pressure, respiration, skin temperature, galvanic skin response). The physiological measurements, and especially the electrophysiological recordings of cerebral electrical activity, provide independent parameters on psychological and behavioral responses. They are also indicative of psychological and physiological states, constituting important control measures for such factors as arousal, activation, or vigilance while tests are in progress and as indicators of longer-term states during the course of the mission. Where possible, on-line results should be available for immediate study by the astronaut undergoing tests or by one of his fellow astronauts.

2. Continued ground-based research is needed on work–rest schedules, sleep, quality of sleep, methods of inducing and regulating sleep, methods of monitoring wakefulness and alertness, relation of sleep loss to performance efficiency, and countermeasures to sleep loss, monotony, and boredom. Emphasis should be on the study of physiological indicators of central neural functioning (electroencephalogram), autonomic neural functioning (various indices), and neuromuscular activity (electromyogram), during wakefulness and sleep and in relation to psychological tests and performance efficiency.

3. Work–rest cycles developed for long-duration missions must take into consideration optimal sleep schedules and other biological rhythms, group dynamics, and morale. Maintenance of usual terrestrial sleep–wakefulness cycles, simultaneous sleep periods, and compatibility of crew members with regard to circadian rhythms are

advised. Preflight training of astronauts and crews should include flight simulations in confinement and isolation, with appropriate operational tasks, sensory stimulation, work–rest schedules, waking- and sleep-state monitoring, and measurement of brain electrical activity (electroencephalogram), autonomic indices, and muscle tension (electromyogram). These data will serve as a baseline and as indicators of potential difficulties.

4. Adequate sleep on long-duration missions is most important. Nevertheless, sleep-inducing drugs or hypnotics must be used with great caution because of side effects. A more promising and healthful approach, not only to the control and attainment of optimal sleep but also to the regulation of waking states of relaxation and alertness when needed, is through conditioning and learning techniques. These procedures should be directed toward control of physical, physiological, and mental states involving muscular relaxation and regulation of activity of the central and autonomic nervous systems. Where sleep cannot be regulated properly, the effects of sleep loss must be combatted by countermeasures planned in advance. These would include exercise, frequent changes of tasks, frequent rest periods, and automatic control and warning devices.

5. Further study must be devoted to the determination of the significance of physiological changes during confinement and isolation, such as reduced alpha-wave frequency and its relationship to cognitive functioning. The possibility that alpha activity can serve as a predictor of cognitive functioning should be explored.

6. Insofar as feasible, every opportunity in upcoming manned missions should be utilized to gain the physiological and psychological data essential to long-duration missions.

6 Skilled Performance

Maintenance of skilled performance in the face of extreme environmental conditions, threatening situations, fluctuations in individual states, and lack of opportunity for practice is a major consideration relative to long-duration space missions. Although scientists and engineers have become more sophisticated about stress–performance impairment questions than during the years following World War II, there are still strong pressures to provide univariate solutions to what are fundamentally complex multivariate problems and to extrapolate from short periods of disuse of learned functions to much longer ones, often unjustifiably.

Sophistication is reflected chiefly in new knowledge concerning the neurophysiology and neuropsychology of arousal and attention mechanisms, the recognition of qualitative differences among various stress mechanisms, and the refinement of criteria. Aerospace scientists have found it necessary to distinguish between discomfort, skill impairment, physiological impairment, and survival effects of various

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states and environmental stimuli. In the analysis of these problems, duration of exposure is recognized as a highly significant variable. For almost every variable in stimulus there is a continuum from arousal and activation, with response facilitation and improved performance, to progressive deactivation, with impairment and disorganization of performance. This makes the study of stress a quantitative as well as a qualitative problem. Finally, with high levels of activation as in emotion and anxiety, there is often disorganization of behavior with accompanying performance decrement.

In the study of skill maintenance and impairment, it is important not only to understand the processes that maintain or impair, but also to specify the relevant associated variables. These include, to mention some of the more prominent, (a) *individual differences* in experience, training, prior exposure, status and relation to the task, motivation, and psychological and physiological resources; (b) *task characteristics,* including difficulty, importance to the operator at the time, and complexity in relation to other ongoing activities; and (c) the full range of *other environmental factors* present in the situation, including other persons directly and indirectly involved, physical parameters, and a host of interacting social, cultural, and group variables.

The published literature, although almost impossible to fit into a common frame of reference, provides a basis for generalizations about the direct and indirect effects of interactions between organism and environment that have been found threatening to the maintenance of skilled performance. While the emphasis in this chapter is on basic ways to mitigate performance decrement (operational techniques for practicing skills are discussed in Chapter 10), identification of parameters of human tolerance and of the factors involved in producing decrement is a necessary preliminary task.

DIMENSIONS OF THE PROBLEM

FACTORS PRODUCING PERFORMANCE DECREMENT

A significant trend in military and aerospace programs has been toward comparatively small, detached organizations operating in relative isolation, frequently in exceptional environments and under unusual task conditions. Even conventional forces have become more mobile and face new requirements of adaptability and skilled performance under more diverse conditions than ever before. The resulting experimental requirements have gone beyond the testing of human endurance to extreme conditions encountered on the surface of the earth to environmental parameters to which man is not developmentally adapted and for which he must make adequate provision not only to survive but also to live comfortably and perform effectively.

The conditions of effective performance are complex. They involve characteristics of the individual with respect to health, fitness, aptitude, training, adaptation, conditioning, and motivation for the task and its environs. On the other side, they involve the demands of the task and the environments in which it must be performed. Extreme deviation in any parameter or combinations of less extreme variation of many relevant parameters could result in the degradation of performance to a point that might impair the accomplishment of a mission. Responsibility for maintenance of effective performance is therefore widely distributed and demands cooperation of all concerned with a mission, including scientists, physicians, nutritionists, engineers, and manufacturers, as well as mission directors.

The parameters affecting skilled performance included in this review fall logically into four overlapping categories, distinguished by their sources and mechanisms, although their interactions are also of major interest. These are (1) components of the physical environment, such as atmospheric mixtures and contaminants, noise, ionizing radiation, and gravity; (2) social-environmental factors resulting from task demands, compatibility, orientation, and location, among which are isolation, confinement, high task load, and sleep deprivation; (3) psychophysiological aspects of individual behavior, such as fatigue, diurnal and other cycles, and nutrition; and (4) reactions to severe threat. The emphasis here is on individual behavior; however, social and group behavior under stress constitute a major related problem.

The specific mechanisms of these "stressors" can in most cases be reported, together with effects that have been observed or tested under particular conditions and with particular criteria. A major advance in the study of stresses in recent years is the recognition of their specificity (see, for example, Broadbent, 1963; Lazarus, 1964; Korchin, 1962; Schaefer, 1962) in contrast to the emphasis on generality and nonspecificity by Selye (1956) and Miller (1960). The action of these mechanisms is dependent on the simultaneous occurrence of other responses with which their effects may combine (e.g., cold and fear) or may partially cancel each other (e.g., noise–overarousing, and sleep loss–underarousing). The motivation of the individual, the support or interference with his motivation received from group sources; his level of physiological adaptation; conditioning and prior experience in the situation; his expectations and confidence in his own reactions, competence, equipment, colleagues, and superiors have significant influence on stress tolerance and performance. Different mechanisms and combinations of them may also be expected to affect different types of tasks differentially.

INTERACTIONS

One reason why well-known stressors such as a temperature of 130°F do not always influence behavior as dramatically in the laboratory as they do in the field is that in real-life situations they do not usually occur in the controlled isolation painstakingly achieved in the laboratory. Although heat is mentioned as the central factor in tropical climes, the actual field environment of the foot soldier in the tropics also includes, in complex profusion, dampness, humidity, insects, jungle hazards, heavy packs, clothing, strenuous work, and perhaps other sources of annoyance, fatigue, and fear. A parallel situation prevails with the astronaut for whom weightlessness may be the primary variable, but it is associated with noise, confinement, relative immobility, and other factors from which it cannot be easily isolated.

While it is scientifically important to understand the specific mechanisms of reaction in order better to understand their interactions with other mechanisms of reaction in complex environmental situations, the ultimate goal of scientific inquiry in support of mission effectiveness must be the understanding of the complex reactions to known complex situations. Present information of this kind is inadequate. Although many offsetting relations have been found, as in the case of arousing noise offsetting the underarousal of sleep loss, most stress interactions appear to have both synergistic effects and secondary overcompensating effects which are often magnified greatly in intensity.

It is necessary to understand that maintenance of proficiency under stress is a goal opposed to the adaptive functions of all physiological and psychological defenses, which may urge the individual to behavioral changes involving control of impulse, abandonment of the task, or at least degradation of performance.

TOLERANCE LIMITS

The limits of human tolerance to various stresses are inadequately known and probably will never be fully determined. Until individual differences are more extensively explored, however, and the combined effects of dedicated motivation, physiological adaptation, and accustomization are fully exploited, the question of possible end points to the extension of human tolerance limits to environmental stress is relative. The importance of this point is emphasized, first, by the differences between average Americans and individuals indigenous to remote areas with respect to adaptation to cold, heat, drought, altitude, and isolation and, second, by the development of "artificial" methods of adaptation, in recent years, to extreme temperatures and to altitude. It is probably true that the austerity and dislocations of personal lives required for these purposes are extremely unattractive to Americans, even in the face of the progress achieved by engineers in overcoming almost all obstacles of the environment that they have attacked to date. In this cultural setting it is perhaps pragmatically necessary, to ensure mission success, to advise the engineers of the levels of the stress variables beyond which protection, support, comfort, and facilitation of human effort must be provided.

Such pragmatic levels can be reported for many variables and situations on the basis of existing data. However, this information is limited and often inaccurate in several respects. One type of error is that tolerance, measured in terms of physiological parameters, may be unrelated to performance of various skilled tasks. For example, it has been found that extreme physiological stress can be endured in some cases without impairment of some performances. The second type of error is that tolerance limits based on "average" individuals, without reference to the range of individual differences, may be seriously distorted. Finally, tolerance limits for any variable, taken singly, cannot be unequivocally accepted for that variable in complex situations. In most cases, the effects of additional stresses are in the direction of lowering rather than enhancing performance efficiency.

APPROACHES TO PERFORMANCE MAINTENANCE

Maintenance of skilled performance in stressful situations is a complex task with many facets, each of which calls on certain scientific disciplines and technologies. Unfortunately, the various approaches frequently have proprietary status among their adherents and must often compete for budgetary support. As a result, the concept has developed in certain quarters that these are to some extent alternative approaches. Nothing could be farther from the truth. Indeed, the measures discussed in this section—selection, adaptation, training and conditioning, nutrition and psychopharmacology, protective equipment, environmental engineering, task systems engineering, psychophysiological monitoring, and organizational management—are interdependent but largely discrete. On one hand, they are concerned with extending human tolerance and human capacity as far as possible and, on the other, with "making up the difference" by providing optimal environmental support and facilitation. Mitigation of stress is one part of the task; the second is a positive approach to maximizing performance effectiveness. Optimal solution of this general problem requires the systematic, coordinated exploitation of all available measures. A realistic view of the goal requires that the full range of possible approaches be included in the analysis. This in turn argues for a systems-analysis approach.

SELECTION

The existence of individual differences in tolerance to any stressor is an invitation to investigate the feasibility of selection. However, the opportunities afforded by this approach have virtually been ignored. For example, in 1953, McCleary, in an experimental study of manual performance at low ambient temperatures (down to −40°F), found that individual differences in loss of digital temperature among his subjects (volunteer basic airmen) permitted computation of a *sensitivity index* of skin temperature loss versus exposure time which discriminated significantly among subjects on performance of the task in the cold. Yet, to our knowledge, no follow-up of this work has occurred. Individual differences have also been found in tolerance to heat and altitude, and—of closer relevance to spaceflight—acceleration, weightlessness, isolation, and sensory deprivation. While it is possible that, in some cases, selection on the basis of other major factors may take precedence over tolerance to a particular stress, the development of batteries of specifically focused stress tolerance tests for selection should be encouraged in an over-all program of performance maintenance.

ADAPTATION

Full exploitation of physiological mechanisms of adaptation and immunization that increase tolerance to environmental stresses would be a giant step in any systematic program of maintenance of skilled performance. When one observes the tolerance of extreme cold by naked Australian aborigines and by strategically clad Eskimos, the altitude tolerance of the Andean natives who work effectively at altitudes around 14,000 ft, and the heat tolerance of desert peoples over the earth, the value of effective programs for adaptation is emphasized. This conclusion is strengthened by work such as that of Davis (1961), who has developed "artificial" methods of cold adaptation which are faster and retained longer than natural acclimitization and are believed to increase resistance to cold injury. Similarly, the possibility of some degree of adaptation to atmospheric contaminants, CO_2, different diurnal cycles, weightlessness, and other critical conditions deserves continued study.

COMPREHENSIVE TRAINING AND CONDITIONING PROGRAMS

A distinction must be made between physiological adaptation, which is under the general control of the nervous and endocrine systems and involves biochemical and cellular change, and other adaptive processes. Natural selection over extremely long time periods has unquestionably been an important factor, for example, among the naturally adapted peoples of various regions cited. The contribution of complex habituation processes and ecologically appropriate behavior patterns of dress, diet, work–rest cycles, shelter, and activity must be emphasized as being of special interest in the present context.

Studies of physiological and biochemical changes occurring under conditions of isolation and confinement with varying degrees of sensory and perceptual deprivation have been reviewed by Zubek (1969b, Chap. 8). There was some suggestion of adaptations, but it is difficult to characterize the results or to generalize from them for several reasons. Durations of confinement were very short relative to long-duration missions. Knowledge or expectancy of the length of confinement seems to play a role, and changes occur toward the end of the confinement period regardless of its length. Motivation apparently has an influence and may be partly responsible for the wide individual differences in the physiological and biochemical changes. It is evident that a great complexity of factors and stimulus variables is involved. Whether such changes will progress with time in space or whether they will stabilize in the long run cannot be predicted from such studies or even from space observations to date. Measurements made in flight for at least six months or a year will be necessary to determine that. All that can be said now is that physiological and biochemical changes, if maintained for a prolonged period of time, will affect the performance of astronauts, and probably adversely. Assuming, for the purposes of this discussion, that the changes will not exceed acceptable limits, what degree of adaptation and preconditioning may be envisaged?

Physical and psychological conditioning and accustomization to the actual environmental conditions in which critical performance is to occur enable the individual to accommodate his performance to the situation. Also education and special instruction may help to develop insight and accurate expectations concerning the task requirements as well as an individual's own reactions, thus eliminating uncertainty and increasing confidence in his ability to perform under the required conditions.

An experimental illustration of accustomization is seen in the study of Clark and Jones (1962), who gave subjects varied thermal experience (warm and cold hands) during three weeks of training on a standard manual task. They found (a) that one day of cold-hand training significantly reduced the size of manual decrement usually encountered with cold exposure, although continued cold experience did not; (b) that skill-level on the task *per se* did not interact with cold-induced performance decrement; and (c) that the thermal conditions associated with task performance appeared to become part of the stimulus complex that elicited complex correct manual responses when the conditions were maintained over a large number of trials. In other words, the subjects learned not merely to perform the task but to perform in particular ways with warm and cold hands. Similarly, accustomization and adaptation would be expected to occur in 0 *g*, provided that possible effects of the spaceflight situation, such as deconditioning or desynchronisis of bodily rhythms were not overriding.

The implications for achieving realism in training programs involving unusual environments cannot be underestimated, as Torrance (undated) and others have pointed out. Perhaps the outstanding example of the exploitation of this approach, including the extensive use of environmental and mission performance simulators, has been the Mercury program in which the complex movements, thrusts, atmospheres, restrictions in work space and personal equipment, and other significant aspects of the mission were effectively simulated in real-time performance on the ground before the first shot. The reports of the astronauts (Carpenter, 1962; Glenn, 1962; Schirra, 1962) in debriefing give ample testimony to the contribution of these preparations to the success of this program. The obvious limitation of ground-based training for long-duration spaceflight is its inability to simulate prolonged weightlessness, a factor that many believe will have profound physiological, if not direct psychological, effects. Extended stays in a space station may be necessary for objective performance testing of astronauts for long-duration missions, for their selection and training, adaptation, and preconditioning.

Accustomization includes so many facets of performance situations that a complete inventory would be out of place in this discussion. The following representative list may contribute to a broad appreciation of the magnitude of the problem. In addition to the parameters of atmosphere, light, gravity, noise, vibration, and the like, other important factors to which accustomization may be desirable include work–rest cycles; body positions and restraints; special diets; water supply; provision for personal hygiene; accommodations for work, recreation, sleep, and rest; communication opportunities and facilities; special restrictions and deprivations (smoking, for example); problems related to personal equipment; and emergency procedures.

Preconditioning may include physical conditioning, use of special diets to control body wastes, isolation to avoid infection and contaminants, altitude, ejection, stress indoctrination, and information on matters of relevance to the total task.

NUTRITION AND PSYCHOPHARMACOLOGY

Nutrition involves at least three important elements: supply of caloric requirements, provision of dietary component requirements, and subjective satisfaction. Research on special diets for hostile environments has demonstrated the critical importance to effective performance of adequate caloric intake and the secondary psychological significance of food.

Seaton's (1962) study of caloric intake of three small (six-man) groups on the Greenland Ice Cap, in which caloric reduction (to 2400 cal/day) resulted in impaired communication within groups, hostility, and increased fantasy and sleeping, demonstrates the secondary effects of inadequate dietary support, over and above task performance.

Food and water requirements are related to temperature, work, and duration of the activity and may impose logistic problems when quantities to be transported or otherwise supplied are large. In situations involving long periods of stress and isolation, problems of boredom and food idiosyncracies challenge the nutritionist to provide palatable meals within the logistic constraints imposed. Food preservation, water purification, and palatability may also increase in importance with time, although much remains to be learned about changes in taste, desire for food, and related problems in long-confinement situations.

The use of drugs to sustain performance is another vast field (Uhr and Miller, 1960) which can only be commented on briefly here. A wide variety of drugs has been studied with respect to properties that sustain vigilance, defer fatigue, tranquilize, prevent or induce sleep, prevent motion sickness, and exercise other effects on behavior and subjective states. Because of the possibilities of deleterious side effects and individual differences in effective dosages and effects, physicans and flight surgeons have been conservative in prescribing drugs for pilots and other operators in critical situations. However, psychopharmacology must be recognized as a significant approach to maintenance of skilled performance under stress and for allaying depression and other reactions on long-duration missions. In cases where small numbers of individuals are involved in highly demanding performances, drug administration could be individually scheduled, based on its effects in representative situations during the preflight training period.

INDIVIDUAL PROTECTIVE EQUIPMENT AND ENVIRONMENTAL ENGINEERING

Problems of requirements for and design and development of protective capsules, life-support systems, personal protective equipment and provisions for habitability, sanitation, food preparation, waste disposal, regeneration of oxygen, food, and water, pressurization, and recreation are well known and widely appreciated. Although many of them are still unsolved, progress in this area has been impressive, and prospects are bright. Environmental-protection, life-support, and habitability engineering may not assure the maintenance of skilled performance, but they will greatly enhance the effectiveness of the other measures toward this end.

TASK SYSTEMS ENGINEERING

This category includes most of the areas usually covered by engineering psychologists and human-factors engineers whose goals are to adapt the system maximally to the facilitation of human performance and to effect an optimal division of labor between man and machine. In multioperator systems it also involves the optimization of interactions among operators for maximum system effectiveness. The principal features of these activities involve (a) *equipment design and positioning,* for instruments and displays, controls, communications facilities, work space, and supporting equipment (see Chapter 3); (b) *systems engineering,* with respect to job definition and assignment of tasks to effect optimal load-balancing, autonomy, and homogeneity of function, scheduling of shifts and work–rest intervals, pacing of tasks, use of task-supporting aides (computers, calculators, slide rules), specification of communications channels and procedures, knowledge-of-results feedback, and other task-relevant information (see Chapter 10); and (c) other provisions for equipment maintenance, redundancy, maintenance of vigilance, mitigation of fatigue and boredom, and maximizing reliability of performance.

The contributions of human factors and engineering psychology and related disciplines have had relatively less impact in certain critical areas, such as aerospace engineering, than those of life support and environmental protection. The systematic exploitation of these disciplines is one of the greatest resources for the general program of maintaining skilled performance.

PSYCHOPHYSIOLOGICAL MONITORING

In sustained performance of unaccustomed duration and under conditions such as sleep deprivation, fatigue, and hypoxia, self-control and performance may be disturbed insidiously and without insight on the part of the operator. In such circumstances, inflight psychophysiological monitoring and warning systems and performance testing may be a significant strategy to protect lives as well as to sustain performance. There are different levels at which performance decrement can be measured or anticipated. The most effective warning system would provide the earliest possible warning. The complex interaction of muscles, nerves, glands, and other systems involved in performance requires much further clarification.

The critical importance of monitoring and effective warning was illustrated in Simons' (1958) Manhigh balloon ascent, in which he was advised by a monitor on the ground to breathe 100% oxygen. This message, based on a telemetered indication of his respiration, is credited with saving Simons' life and the success of the mission.

Some physiological functions and aspects of performance have been monitored through the U.S. manned spaceflight programs, and these data have provided valuable information on the astronauts' continued health and alertness. They could be improved in at least three respects: (1) categorical, quantitative information would be more accurate, whenever feasible, than the analog data requiring clinical interpretation; (2) predictive information, implying the analysis of developing trends and particularly using changes in physiological functions as precursors of performance decrement, would be an improvement over the present basis of monitoring, which is virtually "after the fact"; and (3) information concerning subjective states (alertness, vigilance, composure), as well as physiological function, is needed. Improvements in monitoring technique require further creative research, as the present state of knowledge limits the applications that can be made. An interesting illustration of such an attempt is the approach investigated by Sheer and co-workers (Frazier, 1964), employing operant conditioning techniques as a basis for establishing critical responses to stress.

ORGANIZATIONAL MANAGEMENT

The general approach implied here involves the skilled operator considered both as an individual person and as a link in a complex system. It is widely recognized that motivation accounts for a substantial part of the variations in tolerance to almost every stressor known. However motivation may be characterized, it helps to offset fatigue, lengthens endurance, reduces errors, and counteracts most forces that tend to degrade effective performance. Rather than deal with this important problem at the level of exhortation or naive use of incentives, major attention must be focused on the social situation and factors that have been found to motivate workers in industrial and military situations (Likert, 1961; Herzburg *et al.*, 1959; Myers, 1964; Sells, 1964). It is, of course, recognized that additional motivating influences arise from factors in the general world situation, personal life situation, and the like, but except to the extent that these can be taken into account in the selection process and through organizational measures, they are beyond the control of the types of programs under discussion here.

Work organization provides the social environment in which a man's needs for economic and social security, status, and acceptance and his opportunities for growth, recognition, responsibility, and achievement must be satisfied if he is to commit himself to the performance of his mission with the same zeal that he displayed on his college football team. The challenge here is to organizational management and the command structure to utilize the principles and methods of organizational structure, supervision, reward, and management of human interaction to superordinate the goals of individual participants with those of the organization.

RECOMMENDATIONS

1. The operational and other on-board skills and performances required of astronauts in critical phases of a long-duration mission are so complex and intricate that it is believed that they will suffer degradation under the variety of stresses present unless remedial measures are taken. All phases of this problem should be investigated. This research program should have a multivariate approach and will probably require systems-analysis techniques. Every effort should be made to simulate as closely as possible the actual conditions under which the operational skills and performances will be made.
2. To provide a climate favorable to skill retention and performance maintenance, a bifurcated approach is advised; to mitigate stresses by providing optimal environmental support and facilitation and to seek to extend human tolerances and capacities as far as possible. The latter would involve such measures as educating astronauts in methods of stress control, preconditioning and accustomization, and possibly psychopharmacology.
3. Work should continue on a priority basis to improve the techniques and broaden the scope of psychophysiological monitoring in flight to provide current and predictive information on the astronauts' status and performance and to permit early recognition of potential difficulty.
4. Considering the importance of motivation in maintaining high-level skills and performance, it is proposed that the social situation be utilized, as has been done successfully in industry, through work organization and cooperation by the development of superordinate or group goals.

7 Subjective States

Subjective states—emotion, dreams, imagery, fantasy, hallucinations—are of interest in long-duration spaceflight primarily from the standpoint of maintaining high-level crew performance. Spaceflights thus far have not been long enough or sufficiently devoid of occupied time to provide the necessary conditions for shifting the predominant orientation of astronauts from objectivity to subjectivity. The prolonged cruise phase of a long-duration mission might provide such conditions. The relative social isolation, confinement, empty time, boredom, progressive reduction by habituation of objective anchoring points in the environment, changing physical state due to weightlessness, distortion of the usual balances among sensory inputs, increased preoccupation with home and loved ones, and underlying apprehensions might set the stage for turning an outward orientation to an inner, subjective one. Dissociation and ascendency of intense imagination, prolonged concentrated thought, or daydreams might make it difficult to reinstate a conscious objectivity quickly. The conditioning and reinforcement of such states day after day might prolong them and make them more pervasive.

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Some degree of daydreaming, imagination, and visual imagery is normal to most people and is believed to be an important part of concept formation and creative thinking. Hardly anyone would deny the importance of his subjective states, including his personal and private feelings and his understanding of his experiences. Our concern here is with the role they may play in determining the success or failure of a long-duration mission in space. That is, how they affect the astronaut with respect to his motivation, determination, decision-making and choices, operational performance, and cooperation and collaboration with others. Two examples from past missions may serve to illustrate different aspects of this question. The returned Apollo 14 astronauts, while undergoing the 21-day postflight quarantine, are reported to have exhausted their supply of movies and to have become bored and weary awaiting their release. Apollo 11 to 14 crews in deep space observed unexplained light flashes at the back of their eyes. The initial tendency might be to consider the flashes subjective phenomena; they have since been interpreted as heavy cosmic-ray particles bombarding the retina and optic nerves. On balance, it does not seem likely that astronauts on long-duration missions will become unduly preoccupied with their subjective states or confused between objective and subjective experience, but the topic merits consideration as one of many bearing on the successful accomplishment of extended spaceflights.

THEORY AND OBSERVATION IN IDENTIFYING VARIABLES

It is reasonably clear that psychologists working in the fields of perception, imagery, and thought do not regard experience as unreal, specific only to a single person, and inaccessible to scientific study. Nevertheless, far too little is known about subjective states to provide clear answers as to how they might interfere with a person's management of the objective world. The question seems to break down into two subquestions: (1) What are the factors that encourage the appearance of subjective states? (2) What are the conditions that lead to interference between these subjective states and the individual's ability to manage external reality? If one could present a list of variables involved in each of these questions, with studies illustrating the impact of each factor, it would go far toward satisfying the spaceflight requirement.

One approach to the problem would be to search the literature for studies of subjective experience where the investigators have used situations similar to those that may be encountered in space. For example, an extensive literature of sensory deprivation (see Chapter 4) examines the effects of a variety of types of environmental changes upon subjective experience. However, there is little reason to expect that specific variables studied in what are often very complex experimental settings would necessarily have the same effects upon subjective states in any situation or population. When confronted with such a complex state of affairs, it is risky to attempt to generalize directly from experimental to field settings; the experiments lack ecological validity (Brunswick, 1956). Instead it seems best to concentrate on developing a reasonably simple theoretical paradigm. While the paradigm is likely to be incomplete and incorrect in some respects, it can serve as an analytical device to alert one to factors that may have important effects upon the subjective behavior with which we are concerned. Several paradigms, based upon experimental evidence which in many ways is more regular and carefully controlled than the sensory deprivation data, can be drawn upon.

THE UNITY OF EXPERIENCE

Subjective states have been discussed thus far as if they were sharply different from objective states. This is misleading. All experience is dependent upon processes in the perceiver, and objective experiences—dreams, images, hallucinations, emotions, eidetic imagery, and the like—are generated by or occur in the same fundamental perceptual–cognitive apparatus (Hebb, 1949, 1968). The similarities between the processes allow us to draw on research from all areas of perception and cognition in building a model of this experience-generating apparatus. Moreover, it allows us to use this model to speculate about the factors that may be critical in generating some of the distinctions we make between our different types of experience. It is precisely this type of general model, a model of an experience-generator, that will be most useful in analyzing the conditions that favor the appearance of what we call subjective states.

A MODEL OF THE CONSTRUCTION OF EXPERIENCE

Although experience seems an immediate given, arising as a completed picture or copy of the external world, much research suggests that it is the end product of a complex sequence of information processing (Bruner, 1957b; Neisser, 1967). Experience at each moment in time is something that the individual creates; something that is built using as its ingredients patterned stimulus inputs and a complex store of antecedent traces or neural patterns. This constructive or combinatorial process typically is silent. Under atypical circumstances, however, when stimuli are ambiguous—as in tachistoscopic (brief-exposure) viewing or a noise heard in the night, one may become all too painfully aware of the process of construing and reconstruing stimulus inputs to yield an interpretation (Bruner, 1951, 1957a, 1957b).

Perhaps the key theoretical problems in the area of information processing concern the way in which the stimulus pattern is matched to the relevant stored information. Is it by templates (Neisser, 1967, Chap. 3) or by a parallel process in which various detecting devices simultaneously survey specific features or attributes of the field to match these to past traces (Selfridge, 1959)? While there are no clear answers to these questions, it does seem likely that certain specific neural mechanisms are involved in feature testing, while others are involved in more abstract processes of information storage. Hebb (1968) has speculated that there are three levels of organization in the neural network. The first would involve a kind of iconic or near-pictorial presentation of events (perhaps the feature testers in Selfridge's model). The second, higher level would combine these lower-level assemblies to perceive or experience figures. Higher-order assemblies would include more abstract representations of objects, and these might be the more complex neural organizations that represent ideas or elements in thought. In typical perceptual situations, the sensory inputs would activate the first-level assemblies, resulting in vivid perceptual experience. When there is no external input, the self-generating activity of the nervous system, such as that during the rapid-eye-movement (REM) periods of sleep (Dement, 1965), would bring these same neural patterns into play, the consequence being highly vivid imagery. It is too early to select any one organization of the construction process; more research is needed for that. But abundant evidence (see Neisser, 1967) sustains the key idea that experience involves a process of construction and that the building up of perception depends upon both stimulus and central-nervous-system representations. This, of course, is the critical part of the model.

Many good examples of the constructive process can be found in demonstrations of the transactional perception theorists (Ittleson and Kilpatrick, 1951). One is the rotating trapezoid. When subjects observe a rotating trapezoid that is painted to resemble a window, they see the trapezoid as either rotating or oscillating. They will see rotation if the environment provides distance gradients (binocular disparity, a distinct ground, etc.), which firmly locate the object in space. But if contextual cues are eliminated—the trapezoid is observed in the dark and by monocular vision—it will be seen as oscillating. The assumption of rectangularity governs the perception of the object's behavior. The experience of oscillation also depends upon the strength of the hypothesis that the trapezoid is a rectangular window. Individuals raised in cultures lacking the concept of rectangle and lacking contact with rectangular windows are less likely to see oscillation; they more easily see the trapezoid as rotating rather than oscillating (Allport and Pettigrew, 1957).

Many studies from the "New Look" perception theories demonstrate the interplay of external and internal factors as they control the experience of color (Bruner *et al.*, 1951), words (Postman *et al.*, 1948; Haber and Hershenson, 1965), and distance and size (Ittleson and Kilpatrick, 1951). In many instances the studies demonstrate that strong hypotheses can create experiences that seem objective and yet are inconsistent with reality. But it is wrong to assume that inaccurate experience is always a product of learned hypotheses and ambiguous stimulation. There are undoubtedly many illustrations where the stimulus arrangement creates an inaccurate experience, and learning or forming new hypotheses about reality can be useful in correcting the experience.

In summary, perception is a construction created by a synthesis of patterned stimulation and internal hypotheses or traces. The differences between people's experiences may at times be highly dependent on shifts in the pattern of the external input, as is the case when shifting from observing the trapezoid in the absence of cues from the surrounding environment to observing in the presence of such cues. At other times the difference between people's perception of a stimulus may reflect differences in the hypotheses that they have acquired, as is the case in the perception of the trapezoid by people from different cultural groups. But the perception of each person in each of these cases is a construction involving specific input patterns and specific trace assemblies.

DISTINGUISHING BETWEEN OBJECTIVE AND SUBJECTIVE EXPERIENCE

It was suggested that there is a fundamental unity to experience: all experience, subjective and objective, makes use of the same neurophysiological apparatus. Second, the hypothesis was presented that experience is a construction: it involves the interplay of patterned stimulation and stored traces. Thus, both subjective and objective experience are constructive processes. But there must be some different features to the process if the individual is to discriminate between his objective and subjective states.

The problem of distinguishing the objective from the subjective is further complicated by the fact that all experience is private. Two people cannot come into direct contact with each other's experience. They can only come into contact with each other's overt behaviors. But these behaviors can be used as indicators of experiences. When a person tells you that he saw a green light it would not be unusual to assume that he did indeed have such an experience unless one thought he was deliberately telling an untruth in order to escape a traffic ticket. Even if one can rule out dissimulation, it does not, however, remove many of the fundamental problems involved in knowing what it is that another person is experiencing and what are the stimulus patterns or cues to which he is actually responding. For example, how can we tell if an individual is responding to the wavelength, that is, to the color, of a stimulus? The question seems simple, yet to answer it requires complicated tests and charts to converge upon the cues the subject is using (Garner *et al.*, 1956) and to learn if his overt responses can be accounted for by changes in the wavelength rather than, say, the luminance of the stimulus. In fact, much of the research in perception has to do with extracting biases from indicator responses so that one can arrive at unbiased estimates of the thresholds and discriminative capacities of the organism (Galanter, 1962; Tanner and Swets, 1954).

The privacy of experience is importantly related to the issue of discriminating between objective and subjective states. If all experience is constructive and uses the same apparatus, then there have to be some features of experience that the perceiver himself can use to decide if his experience is objective or subjective. But suppose for a moment that we decide to make this decision for him. We cannot see his experience; we only see his response. How could we tell if his response reflects an objective or a subjective state? The answer is simple: we would check his verbal report against our own experience. We would see if something in the environment is responsible for that verbal report. If his report disagreed with our evaluation, we might think that one of us was in error, that one of us was basing his reports on a subjective experience. If our subject had just emerged from stage 1 sleep, with rapid eye movements displayed on the polygraph, and he then reported an experience different from anything we had just had, we would define his experience as a subjective state called dreaming. We would have no difficulty, therefore, with the discrepancy between the two reports of experience, as his report would be clearly attributable to a subjective state.

One is in somewhat the same relationship to his own experience as a person observing him from the outside. There is nothing that is necessarily subjective or objective about his experience. There is no signal in his perceptual field that says "This is a dream," "This is real." His ability to discriminate his dreams, emotions, thoughts, images, moods, fears from outside or objective impressions is arrived at by a constructive or decisional process that probably has features in common with perception itself. The clarity of experience *per se* is not an adequate guide for the reliable discrimination between subjective and objective states (Hebb, 1968; Singer, 1966): some internal experiences are quite clear (dreams), while others are quite vague; and the same is true of objective experience. What processes, then, are likely to aid the perceiver in this discrimination? They are probably similar to those we would use as outside observers. The perceiver has to compare the experience against other experiences and in this way identify its cause. For example, when one awakens from a dream, he is usually aware of the dream images. Because the cerebral cortex is alert or activated during the dreaming of stage 1 sleep, awakening from a dream tends to be abrupt, and the dreamer is immediately and fully aware of his surrounding environment. There is such a clear and distinctive shift in the content of awareness, together with the perception of himself in bed, that he is highly unlikely to confuse his internally generated dream with his externally created percepts. But should he awaken slowly, after a vaguely perceived set of images, from stage 2 or 3 of sleep, and only gradually become aware of the contours of his external environment, he may indeed find it difficult to discriminate sharply that which is subjective from that which is objective.

The perceiver thus has available a variety of cues that allow him to locate the subjective or objective causes of a particular experience. He goes through a process of comparing a particular experience (e.g., visual experience A) to earlier and to later experiences. He may try checking his visual experience A against other nonvisual experiences—Did he hear something? Can he touch something? Cross-sensory matching, comparison with other experiences, and observing the conditions under which he had the experience (was he lying down, in bed clothes, was he tired, anxious) are all involved in making a judgment about the objectivity or subjectivity of the experience. If the experience is objective, he can attribute it to a specific event in the environment. If the experience is subjective and cannot be attributed to an external event in the environment, he will attribute it to some event within himself.

THE RESPONSE TO SUBJECTIVE EXPERIENCE

Once the attribution is made (and in most cases the attribution occurs rapidly) the individual is prepared to act on his experience. If he knows that a state was subjectively elicited, he can ignore it in making decisions about the world. Recognition of the subjectivity or objectivity of an experience is probably the first important step in dealing with potential interferences by subjective states with performance in the objective world. But it may not be the only step. There are a variety of internal sources to which subjective experience can be attributed, for example, being emotionally upset, tired, or lonely. If the individual is unclear as to which of these is the cause of his experience, or if he is concerned about becoming emotional or lonely because he does not expect to become that way or because he has concerns about the meaning of becoming that way, he may experience the subjective states as threatening and highly distressful. Thus, he will have difficulty dealing with his world not just because he cannot distinguish the objective from the subjective but because he finds the subjective disturbing.

There is some suggestive evidence of this effect in sensory deprivation studies. Among volunteers who quit the experiment, those who quit somewhat later in the deprivation period are very much more distressed than nonquitters or than people who quit very early (Zubek, 1968). These different levels of disturbances show up on a variety of measures including steroid outputs. All the subjects probably have uncomfortable and odd experiences: confinement and exposure to little stimulation produce changes in mental activity. But some of the subjects—the late quitters—find the changes disturbing, while others apparently do not. In fact, Wright and Zubek (1969) claim that the quitters are almost all persons with strong tendencies to produce primary process imagery and with poor control over such imagery. Everyone has daydreams, images, and odd thoughts, but some are more bothered by them than others.

Experiences serve as a basis for planning action, and this planning, acting, or competency mechanism can be brought into play either by subjective experiences or by objective experiences. Whether the resulting behavior is competent or disorganized will depend on (1) properties of the so-called competency mechanism and (2) the clarity of the information to which it is responding. The more clearly we can denote experience as objective or subjective, the more easily we can decide how to behave with respect to it. But even if the subjective nature of certain experiences is clearly seen, difficulty in accounting for their appearance (problems in attribution) or particular meanings or interpretations of the experiences (e.g., I'm having hallucinations and am going crazy) can stimulate distress and result in a breakdown in coping behavior.

A MODEL FOR RESPONSE TO SUBJECTIVE AND OBJECTIVE STATES

A recently developed model (Leventhal, 1967, 1968, 1970) attempts to identify the relationship between emotional behavior and reality-based, problem-solving behavior. With respect to danger, a person's first response in confronting the situation involves the interpretation or appraisal of it as a danger. The threat is not built into the stimulus. As Lazarus (1966) and his colleagues have shown, the threat response, as measured by verbal reports of fear, galvanic skin response, and change in heart rate, is dependent on the individual's cognitive appraisal of the situation. This appraisal factor can be altered by instructions; the same stimulus can result in stronger or weaker stress reactions depending upon the subject's prior set or preparation.

Once the individual evaluates the situation as a danger, he will make a variety of responses. These responses are relatively independent of each other and occur at several levels of reaction, cognitively and internally. The responses, therefore, are a product of the interpretation. If the subject focuses his attention on the external features of the situation, he will be concerned with the danger itself, its consequences, probability, and control. His behavior will be guided by cognitive danger information, that is, objective features (as he sees them) of the external situation. If he focuses on his own internal responses and becomes fearful, it will stimulate concern with the control or elimination of emotional discomfort. In attempting to moderate his discomfort, he may select information and be guided in directions quite different from those in the former instance. "Danger-control" and "fear-control" describes these two types of concern. Danger-control is concern with objective perception. Fear-control is concern with subjective states. Each of these concerns can translate itself into action, and it seems that the taking of action, the action selected, and the vigor and skill with which it is executed are highly dependent on the individual's coping skills. These coping processes or skill systems appear to be relatively independent of the initial experience (fear or danger) that is motivating them.

CONFLICT BETWEEN OBJECTIVE AND SUBJECTIVE STATES

Perhaps one of the most serious problems that faces the individual in adapting to a difficult situation is the appearance of conflicting behavioral tendencies. The objective demands of a situation may require approaching a source of danger in order to remove the threat. The subjective demands of fear may produce strong desires to avoid any contact with the agent of danger. When the need to control subjective states is dominant, avoidance behaviors may interfere with meaningful coping behavior. Avoidance reactions of this sort have been recorded in a number of fear-communication studies (e.g., Leventhal and Niles, 1965; Kornzweig, 1967) and were discussed at length in theoretical articles by Miller (1944, 1951). Loss of hope (Overmier and Seligman, 1967) may also occur under conditions of strong threat. This condition of paralysis of the coping system seems to arise from the experience of severe punishment under conditions where escape is impossible. Once established, it prevents the organism from coming into contact with information that would make it clear that coping is possible. Reactions suggestive of loss of hope have been reported in studies with rats and dogs (Overmier and Seligman, 1967), and similar responses have been observed in humans. Such reactions seem to be a product of interactions between strong situation-stress and factors such as poor coping skills, low levels of esteem (Leventhal and Trembly, 1968), or strong feelings of vulnerability to danger (Niles, 1964).

Conflict between danger-control and fear-control seems to be fairly common and is costly to the organism. Exposure to danger and vacillation between the demands of the situation and the competing demands of strong feelings or affect preclude successful handling of the threat and, as a consequence, ensure continuing high levels of energy expenditure. But these factors need not conflict. In many situations they alternate; the individual first attends to the demands of the objective danger and then turns to the management of his subjective fears. In others the order may be reversed; managing subjective states of fear may be a necessary prelude to the successful manipulation of the danger. Examples of the first type are common with the sudden onset of danger and in situations where the individual is reasonably well prepared for control of the objective environment. An example of this is seen when a skilled driver suddenly loses control of his car. The recognition of danger immediately gives rise to various adjustive behaviors: wheel turning, brake tapping, accelerator tapping, and the coordination of these actions with the rapidly shifting visual field. While the driver is thus occupied he is unlikely to become frightened. Those parts of his body that are coping with the external world are too busy to be "scared"; his arms, hands, and feet are too busy to shake with fear. Moreover, he is unlikely to notice those parts of the body–the face and stomach–that are "frightened." But once the danger is brought under control, the individual may become quite frightened. His arms and legs shake, and he clearly notices his bodily arousal–increased rate and depth of respiration, a rapidly pounding heart, sweating palms, and the like. In light of the preceding events he can readily interpret or react to this arousal as a state of fear. Now that he is afraid and recognizes it, he may decide to do something to control it–have something to eat, sit and relax, or have a drink, for example.

The opposite sequence of events has been reported in other situations. For example, Funkenstein *et al.* (1957) found that some of their subjects initially showed rather strong emotional reactions to stress, gradually brought these responses under control, and then successfully coped with the situation. Epstein (1967) in his studies of stress responses in sports parachutists presents considerable data suggesting that the experienced sportsman differs from the novice in his ability to control or suppress his fear. The experienced chutist presumably becomes fearful in the morning of the day he decides to jump. As jump time approaches and during the jump itself he experiences a state of excitement and enjoys managing himself in a graceful dive. Epstein postulates that control of the fear state is due to a strong inhibitory mechanism. It may also reflect the fact that the chutist is too active with the business of coping with reality to become fearful; so he acquires skill, and the skill suppresses his affect. The latter interpretation seems plausible from our theoretical model;

it would interpret Epstein's skydivers as having substituted danger-control for fear-control. It is also supported by some recent data collected at Wisconsin by Ouchida who found, unlike Epstein, the skilled chutists reported as much fear as unskilled chutists in the moments after they pulled the device to release their chutes, a period during which they must passively wait for the chute to open.

It seems clear that some sort of regulatory mechanism must be present for the satisfactory alternation between danger- and fear-control behaviors. When this breaks down and the individual attempts to cope simultaneously with the demands of the objective environment and the pressures of his emotional state, it is likely that neither task will be satisfactorily accomplished. Thus, while the threat situation may simultaneously elicit many of the behaviors that make up the fear response and the behaviors that comprise the coping reaction, successful problem-solving activity seems to require the organization or concentration of the total organism on one or another of these demands in some serial order.

FACTORS ENCOURAGING OBJECTIVE EXPERIENCE

Realistic perception, and the application of coping skills to the demands of external reality, can clearly dominate the individual's perceptual and behavioral system. What conditions favor this? Two types of condition would seem particularly important. The first set involves factors that maintain the clarity of external stimulus inputs. The second set includes factors that keep the organism tuned to act upon objective experience.

When external cues are clear and distinct, perceptual experience is likely to remain objective; it will track the external inputs. But what is a clear external situation, and what would it be in the confines of a spaceship? Clarity is undoubtedly related to the consistency of the information being received by the individual's various senses. Visual, auditory, and kinesthetic sensations typically reinforce one another for the construction of a stable world. In space many of these cues are modified or absent, in particular those cues relating to spatial and temporal orientation. Substitutes, however, are readily available. Keeping records according to fixed clock time and developing up-down coordinates relative to specific stellar bodies are examples of ways of creating a stable frame of reference for the environment of the ship. Astronauts are trained in techniques for maintaining clear temporal and spatial orientations (e.g., staying with Cape time), and further methods are improvised in flight. The complex internal environment of the spacecraft and the continuing observational demands of space experiments provide rich environmental stimulation. Simply maintaining this orientation is a sufficiently important step in maintaining an organized and externally directed behavioral system. Maintenance of this type of behavioral disposition is somewhat circular: acting in an externally oriented manner is likely to be self-reinforcing. If one is plotting intersteller distances, one is unlikely to become disoriented in space and time and become absorbed with subjective experiences. The act of coping with reality will lead the individual to see himself as reality-oriented; the behavior is self-defining (see Bem, 1967).

FACTORS ENCOURAGING SUBJECTIVE EXPERIENCE

As the external stimulus field becomes ambiguous or unpatterned, as in sleep or in perceptual deprivation, internal factors will dominate the process of experience construction. This is undoubtedly responsible for the reports of visual sensations and hallucinations in the perceptual deprivation situation (Zuckerman and Cohen, 1964). The appearance of dreams and other strong visual imagery reflects the activity of the cell assemblies that are involved in the storage of perceptual hypotheses. As noted earlier, Hebb (1968) speculates that on some occasions the activity in assemblies at the second or third levels of organization may become strong enough to recruit activity in the first level, i.e., the trace assemblies involved with external stimulus input. He also suggests that motor activity, particularly eye movements, facilitates the arousal of these first-order assemblies. It seems that external stimulation must be eliminated if these first-order assemblies are to be governed by the activity of the internal system. But the removal of external stimulation is only a precondition for such events; it does not ensure it.

Of course, there are other sources of stimulation than the external environment; our discussion of fear assumed that the organism's own behavior serves as a source of stimulation in constructing subjective emotional states (Mandler, 1962). Because emotional states are dependent on internal bodily stimulation, these experiences take on an objectivity that may be absent with visual activity, which is primarily dependent upon central states. The activity of the stomach, sweat glands, and heart during fear is objectively palpable. Indeed, these internal signals sometimes induce external changes, as in posture and facial muscles, and are visible and subject to social validation. In dealing with subjective emotional states, the problem therefore is that of defining the cause and potential consequences of the state and not, as has been suggested in the past (Schacter, 1959), of determining whether one is emotional or frightened. When the internal cues are clear, as in strong emotion, there is relatively little difficulty in identifying the subjective nature of the experience. This will be of help in sequencing one's behavior; action appropriate to the control of fear rather than the control of danger can be taken in a relatively deliberate manner.

The remainder of this section will consider briefly a number of factors that are involved in generating subjective states from objectively produced experiences. Successfully identifying the cause or source of an experience (attributional process) seems to be of critical importance to the appearance of effective behavior for the control of the environment or of the subjective state itself.

Cue Location The presence of strong cues defining internal informational sources will be an important determinant of subjectivity of experience. When an experience is accompanied by a fast and strong heart beat, hand shaking, trembling, sweating, and such reactions, there will be a tendency to regard the experience as having a strong subjective component.

Cue Salience The awareness of internal cues depends upon their salience relative to external cues. The stronger the internal responses and the weaker the external responses, the greater is the possibility that the state will be perceived as subjective. Strength of internal responses can be affected by the signal source, attentional set or readiness to detect particular cues, social factors such as consensus on certain cues, and other influences. It seems that an individual is more likely to notice internal cues when these cues are disproportionately strong relative to the eliciting conditions.

Self-reflection If by training or experimentally induced set a person learns to pay close attention to his body cues and becomes quite conscious of them, he is likely to have a clear idea of the subjective nature of his experience and behavior. Under these conditions, he is unlikely to confuse his subjective state with external reality. For example, making a person aware of his laughter during a movie or cartoon will increase laughter but decrease his tendency to think that the movie or cartoon is funny—the self-aware person does not allow his subjective response to influence his perception of the external reality (Leventhal and Mace, 1970; Leventhal and Cupchik, 1970).

Prior Expectation or Set Sets have two important effects on the apparent subjectivity of experience: they can change the subject's appraisal of a stimulus so that he becomes more or less emotional, thereby influencing the degree of internal stimulation (Lazarus, 1966); and they can effect the attribution of experience to external or internal cues by focusing the subject on particular input patterns and encouraging him to see them as linked to specific antecedents. Two good examples of the latter type are studies by Schacter and Singer (1962) and by Schacter and Wheller (1962). In the former, subjects ignore or fail to imitate the emotional behavior of a stooge if they are prewarned about the bodily changes that will be produced by an injection of epinephrine; the information focuses them on their bodily responses and provides an accurate attribution. In the second study, subjects ignore (as in the self-reflection study) their drug-induced emotional behavior (they are made to laugh or not laugh by two different drugs) because their clear expectations and knowledge of the external stimulus lead them to attribute their emotional response to some other irrelevant source. Similar effects are shown in studies of response to electrical shock (Davison and Valins, 1969; Nisbett and Schacter, 1966; Ross *et al.*, 1969). In all cases the subject is focused on aspects of his emotional behavior in stress settings. Instructions are used to attribute these behaviors to something other than strong shock, and in all cases the subject can ignore his subjective or emotional behaviors to the threat stimulus and cope more effectively with external reality.

Personality Disposition There are wide varieties of personality characteristics that may bear on an individual's readiness to detect the subjective aspect of experience and differentiate it from the objective or external. These dispositions do not represent a separate class of factors from those already discussed but are lasting individual differences in the tendency to exhibit features of the processes already under discussion. For example, there may be important individual differences in sensitivity to different types of internal or external cues (Schacter and Gross, 1968) and in the ability to analyze and separate different features of the perceptual field, e.g., field dependence and field independence (Witkin *et al.*, 1962). Specific familiarity and experience with particular internal states, such as day-dreaming and fantasy, may also be important to set and prepare people to deal with them under long-term isolation or boredom (Singer, 1966). It would seem, however, that personality disposition *per se* will be of relatively little importance in spaceflight. Astronauts are highly selected, and training and the expectations it creates are probably more important than these traits.

Social Factors The social environment and the type of validation and support people give one another can clearly influence the appearance and relevance of subjective states. For example, the same drug has quite different effects on mood in different social contexts (Nowlis, 1958). In spaceflight as in most situations, it is likely that experience of the subjective will be kept private, while that of the objective will be shared. This in and of itself will facilitate discrimination between the two and help to avoid conflict between objectively and subjectively based needs. Some sharing and validation mechanism might be built into the group, however, in order to ensure that there is no harmful spillover from one domain to the other.

RECOMMENDATIONS

1. Research on subjective states relative to long-duration missions should emphasize identification of all the factors likely to favor the ascendancy of subjective states under such conditions and the procedures or techniques that might be adopted to minimize them or prevent their interference with performance of the mission.
2. Astronaut training should include education about the nature and significance of subjective states, factors that favor them, and ways in which to recognize and cope with them.
3. During space missions, provision should be made for recognizing and identifying subjective states in order to detect any problems of this nature at an early stage.

8 Group Processes and Interpersonal Interaction

An inquiry into factors determining the adaptation of man to prolonged spaceflight must take into account, among other things, his social and cognitive nature. This requires going beyond the biological model that has dominated most of our thinking in space-vehicle design, and even beyond the individual adaptation model that has characterized must of our thinking regarding the psychology of such an undertaking. A two-year manned mission clearly must constitute a closed ecological system capable of long-term viability.

Design engineers addressing themselves to the provision of such a system have long recognized the importance of biological requirements of man and have developed an impressive technology for atmospheric control and nutrition and are diligently striving to solve the waste-managment problem. A concern for the apparent deconditioning resulting from weightlessness has initiated a search for engineering or life-sciences solutions. Some well-known and several less well-known physiological needs, however, have attracted considerably less of the attention of space scientists and engineers. These

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include sex, the need for sensory stimulation, and the need to exercise perceptual-motor skills in order to maintain them.

The amount of attention given to important human needs in the design process decreases rapidly from a great deal of attention paid to very basic physiological needs to essentially no attention at all given to higher-level needs such as those described by Maslow (1943) and related to isolation research by Haythorn (1969). The social needs of man—the mutual interdependence among crew members for need satisfactions—have been largely neglected. This has been due primarily to the individual psychology model prevalent in American psychology and to our profound lack of knowledge regarding the important symbiotic relationships that exist between and among members of any social group. An examination of the limited information available bearing on factors supporting or disrupting these mutual interdependencies, however, may help to identify problems to be encountered in this area on long-duration manned spaceflights, suggest possible solutions to such problems, and focus attention on problems requiring further research.

A fair amount of good research emphasizes the importance of superordinate goals in maintaining in-group cohesiveness and minimizing intragroup hostility (see, for example, Sherif, 1951; Sherif and Sherif, 1953; Sherif *et al.*, 1955; Deutsch, 1968). The superordinate goals (i.e., goals that are compelling for all group members but that require interdependent activity for attainment) of survival and mission accomplishment are seemingly quite clear in the case of space missions. However, other data, to be reported below, suggest that time may be a highly relevant variable in the perception of superordinate goals and that a strong tendency exists for progressive social withdrawal and individuation in conditions of long-term group isolation and confinement. Since systematic studies of isolated groups have been limited to relatively short durations, it is not known how far this process goes. It is also true that no studies in the literature have used as subjects men as highly selected as our astronauts. Until it has been checked in orbital flights or otherwise, however, the possibility must be considered that a mutual withdrawal and encapsulation process may proceed over time to such a point that superordinate goals and interdependencies are de-emphasized to the extent that they no longer maintain group viability. In the light of current knowledge regarding the importance of feedback in adaptative systems or of reinforcement in behavior modification, it can be safely presumed that adaptative interpersonal relations will depend on interpersonal communication, whether verbal or otherwise. This process of social withdrawal and individual encapsulation seems very likely to impair appropriate interpersonal communication.

THE DEVELOPMENTAL SEQUENCE

A human group in a particular environmental setting will go through a developmental adaptation process wherein individuals adjust to each other and to the environment. Many studies have been directed to this group development process, in a variety of environmental circumstances. Tuckman (1965) presents a recent review of this literature, identifying four stages of group development common to a variety of groups in a variety of situations. These four stages he labels as follows:

Forming The early stage of group formation wherein individuals get acquainted and orient to each other and the environmental situation.

Storming A common phase of grouped development, particularly for problem-solving groups, wherein individuals work out interpersonal hostilities, dominance struggles, differences of opinions on relevant issues, and other aspects of interpersonal stress and threat. (This phase is characterized, as the name implies, by interpersonal hostility, aggression, and expressions of differences.)

Norming A phase succeeding the storming phase and characterized by the development of shared values, role expectations, codes of conduct, and the like.

Performing The phase wherein individual roles have been defined, functional specialization has developed, and the details of functional interdependencies have been clarified to the point that the group can function effectively in accomplishing its tasks.

The studies reviewed by Tuckman dealt predominantly with *open groups,* i.e., groups in which members had considerable access to the world outside the group. These were therapy groups, discussion groups, work groups, military groups, and decision-making groups. There is no reason to doubt, however, that the same developmental sequence occurs in isolated and confined groups, except for the observations made by Rohrer (1961) and Mullin (1959) that men wintering over in antarctic scientific stations seemed to suppress interpersonal hostilities apparently at the cost of developing various psychosomatic ailments.

It is not at all clear, however, that the end product of group development under conditions of isolation and confinement bears any resemblence to the end product under other circumstances. These other groups have an external, changing reality to which they must constantly adapt. Differences between the group's perceived and desired environmental circumstances provide an impetus to adaptative behavior, thereby reinforcing the perception of functional interdependence among group members. In the relatively unchanging circumstances of a long-duration spaceflight, there would seem to be very little in the way of a requirement for adaptative behavior. There would thus perhaps be very little in the way of reinforcement for perception of functional interdependence. Under these circumstances, the social withdrawal and encapsulation observed in laboratory groups by Altman and Haythorn (1967a) is not unlikely. These processes, which seem to have an interpersonal stress-management character to them (Haythorn, 1970), tend to make an already stimulus-poor environment even more so, inasmuch as crew members, by withdrawing, provide less stimulation for each other. A great many data indicate that reduction of stimuli, particularly in the extreme cases of stimulus or perceptual deprivation, produces a high level of stimulus-seeking behavior (*cf.*, Jones, 1969; Smith *et al.*, 1967, 1968; Vernon and McGill, 1960; Zubek, 1969a). It has been observed both anecdotally and in laboratory studies that in socially isolated groups the degree to which men seek and obtain stimulation in the form of interpersonal information may in itself create problems in that men become "overexposed" to each other (Byrd, 1930, pp. 16–17; Smith, 1969; Altman and Haythorn, 1965). This overexposure may result from an accelerated rate of information exchange relative to the rate at which group members are able to developed shared values, behavioral expectations, and belief systems (the norming phase of the Tuckman sequence). An accelerated rate of information exchange may produce interpersonal stress which in turn produces or at least is accompanied by social withdrawal and encapsulation, thereby heightening the degree of stimulus reduction.

It is not at all clear that this process reaches a steady state. The progressively lower levels of stimulation occasioned by the process of social withdrawal and encapsulation would presumably make the data of stimulus and perceptual deprivation studies even more relevant. Such studies now clearly indicate that highly significant psychological changes occur in the adaptation of man to extreme degrees of stimulus reduction. In reviewing these studies, Zubek (1969a) reports a highly significant slowing of the EEG alpha rhythms, accompanied by a decrease in reported arousal levels but an increase in arousability, i.e., in sensitivity to existing stimuli. Zubek reports that studies of sensory and perceptual changes under conditions of stimulus and/or perceptual deprivation, though occasionally inconsistent with each other, generally find an increase in auditory, cutaneous, olfactory, and gustatory sensitivity. An improvement in performance on vigilance tasks, reported by Johnson *et al.*, (1968), though seemingly incompatible with the decreased arousal levels generally reported by sensory-deprived subjects, may be a function of the heightened stimulus-seeking orientation and the greater sensitivity to existing stimuli. (See Chapters 4 and 5 for further discussion of these points.)

One might expect that a program of stimulus enrichment could be easily designed to offset these effects of stimulus reduction. In fact, research has been reported by Myers (1969) in which subjects under conditions of complete silence and darkness for seven days were compared with subjects similarly confined but under conditions of stimulus enrichment. As expected, the stimulus enrichment essentially eliminated the deleterious effects of the stimulus-deprived confinement. These results must be viewed cautiously, however, in light of the relatively short period of confinement and in view of Jones's (1969) observation that the drive underlying stimulus-seeking behavior in stimulus-poor conditions is for "information" rather than "stimulation" *per se.* It would seem that the amount of information contained in stimuli decreases with increased familiarity and increases with meaningfulness or relatedness to the individual. It would thus appear that any stimulus-enrichment program for a long-term period of isolation would have to provide stimuli that were both novel and significant to the individual.

A closed system, if viable, will eventually reach a steady state. Viewing the isolated group as a closed system (or miniworld) raises the question of whether and how the group will stabilize, i.e., reach a steady state. In a strict sense, of course, the miniworld under consideration will not reach a steady state. Food reserves are being depleted, as are fuels and chemicals required for atmospheric control and water cycling. The human components will be aging, if nothing else. Obviously, only a heterosexual grouping could be indefinitely viable. Even aside from these very-long-range considerations, however, there remain unanswered questions regarding the stabilization that such a group of individuals would be most likely to achieve. The tendencies toward individuation and hypoarousal, if allowed to go unchecked, could seriously impair if not destroy group effectiveness. Research aimed at better understanding and control of these processes is very much needed.

The concept of the miniworld contains implications that require explication at this point. As has been observed by Fuller (1968), man already lives in a huge spaceship called Earth. Spaceship Earth is presumably capable of providing all man's needs, primarily because man and his needs have evolved interdependently with other life forms and other physical features of the planet. The smaller world we design for space travel should also be capable of satisfying all man's needs, at least for the length of time required for the trip. Determining whether such a capability has been provided requires a prior determination of what needs must be met. Unfortunately, no completely satisfactory taxonomy of human needs has yet been advanced. The taxonomy advanced by Maslow (1943), however, has gained rather wide acceptance and seems to provide a useful starting point for examining the long-range autonomous visibility of a miniworld. Maslow's classification of needs is a hierarchical one, in the sense that lower-level needs are presumably more important to the organism than are higher-level needs. Maslow argues that higher-level needs do not become salient unless lower-level needs are reasonably well satisfied. Various levels of need can be activated simultaneously, but frustration of needs lower in the hierarchy tends to focus the organism's attention on seeking satisfaction of those needs to the temporary or even permanent neglect of higher-level needs. Maslow's hierarchy places physiological needs important to the survival of the organism at the lowest level. When these physiological survival needs are reasonably well met, safety and security needs are said to assume salience. When these also have been satisfied, needs for affection and belonging come to bear. Esteem needs are next in the hierarchy, followed by needs for self-actualization or self-realization. In Maslow's view, few individuals achieve satisfaction of these needs for self-actualization. When self-actualization needs have been reasonably satisfied, however, cognitive and aesthetic needs are said to become salient. Obviously this hierarchical schema includes the possibility, or even the probability, that men may live out their lives without ever achieving satisfaction of higher-level needs. Even more, higher-level needs may never even become salient for the majority of men who must struggle to obtain minimal physiological and security requirements. Nevertheless, it seems worth examining the degree to which our engineered miniworld is capable of permitting satisfaction of high-level needs. This is particularly germane to a discussion of group development because many of the higher needs are essentially social and cognitive in nature, requiring a model of man that has not been common in vehicular design consideration.

We have already mentioned some of the long-range physiological changes accompanying stimulus reduction and weightlessness. These changes suggest that subtle physiological requirements of the human organism exist, which, if overlooked, could result in deactivation of the organism, decalcification of its skeletal structure, and atrophy of its muscular systems. More relevant to our current concern with social and psychological factors are the various subtle requirements for orienting to reality and maintaining a self-concept that permits appropriate responses to the physical environment and other people. Men engage in continuous reality-testing, interacting with the physical environment for this purpose when possible, but otherwise looking to other people to confirm the reality of these perceptions (see Chapter 7). The unreal world of a tiny capsule far from nowhere, with a very limited number of other people with whom to compare notes, would seem to impede normal reality-testing.

Needs for affection and esteem are demonstrably important to individuals. In addition to the role others may play in social reality-testing, obviously needs for affection and esteem can only be satisfied in a social context. It therefore behooves us to examine the mechanisms by which interpersonal relations are maintained, perhaps thereby identifying ways of preventing the withdrawal and encapsulation processes mentioned above. It seems reasonable to expect that a prolonged period of perceived lack of affection and esteem from others would lead an individual to regard himself as unlovable and unimportant. Such a self-concept is seen clinically to characterize relatively ineffective, poorly adapted individuals. Further, experimental studies have shown that self-esteem can be manipulated successfully by relatively weak laboratory techniques, and that these manipulations can significantly influence a wide variety of social behavior, such as persuasibility, interpersonal attraction, morality, academic performance, sociometric choices, leadership, affiliation, and compliance (*cf.*, Wylie, 1961, 1968; Janis and Field, 1956; Abelson and Lesser, 1959; Zimbardo and Formica, 1963; Coopersmith, 1967; Berkowitz and Lundy, 1957; Nel *et al.*, 1969; Helmreich *et al.*, 1969). The relative ease with which self-esteem can be manipulated in the laboratory, and the pervasive effects that these manipulations have on behavior and subjective reports, emphasize the importance of these higher-level needs.

The concept of self-actualization, although difficult to define clearly, seems to involve an adaptation to life that effectively exercises the unique interests and abilities of the individual in a meaningful way, i.e., in a way that provides a high degree of interrelatedness among the various areas of the individual's life-space. He fits his niche, so to speak, bringing his interests, skills, and personality predispositions into play in ways that are intrinsically satisfying to him. This involves the individual's total life-space. To the degree that his life-space is based on interactions with a physical and social world, it involves his total adjustment to the physical and social world around him. It can be safely presumed that members of crews on long-duration space missions will be highly capable individuals, used to coping with realistic problems. It seems unlikely that such individuals would readily find opportunities for self-actualization simply as passengers on a long-duration mission during most of which time they have little or nothing of an actively useful nature to accomplish. So-called "Mickey Mouse" tasks would not provide the realistic challenge such individuals may require to maintain their active orientation to reality. Perhaps some realistic tasks could be provided, however, such as the construction en route of a larger capsule assembled from components prepackaged on earth. Extravehicular assembly in space might be challenging and time-consuming enough to keep the crew engaged throughout much of the mission period. This suggestion is offered less as a serious proposal than as a stimulus to thinking about the problem. Design engineers could surely come up with many other such thoughts. The goal here is to provide a realistic, challenging task that will keep crew members meaningfully involved in interdependent activities directed toward a superordinate goal. The mission itself constitutes a superordinate goal, as mentioned earlier, but does not require a high degree of interdependent activity en route.

Educational and recreational opportunities would, of course, facilitate long-term viability. The importance of providing opportunities for privacy is difficult to assess. Jointly confined individuals frequently express a desire to get away from each other. However, in a study by Taylor *et al.* (1968) addressed to determining, among other things, the effects of privacy versus no privacy on isolated groups, privacy was found to play no significant role by itself but interacted with other aspects of isolation in such a way as to suggest that joint confinement without opportunities for privacy served to mitigate the stressful effects of having no outside stimulation and expecting a long mission duration. In this same study, the authors provided the best direct experimental data available bearing on the importance of outside communication. In their laboratory groups, they found that outside contacts in the form of verbal instructions for tasks, requirements to communicate verbally to a mission control center on tasks, provision of popular music and 5-min excerpts from an outdated Huntley-Brinkley report significantly reduced the reported subjective stress and the likelihood of the group requesting early release from the experimental conditions. These data support the anecdotal observations regarding the importance of outside radio communications in Antarctica and suggest that a strong emphasis be placed on providing as much communication with earth as possible (see also Chapter 10).

INTERPERSONAL NEEDS AND INTERPERSONAL STRESS

Men are, among other things, highly social animals, using each other interdependently as sources of stimulation, sources of satisfaction of social needs, and environmental manipulanda to be managed and controlled in accomplishing one's own ends. These aspects of the social nature of man have been discussed elsewhere (Haythorn, 1968). In the context of group development and stabilization for long-duration missions, it should be noted that interpersonal needs exist which predispose group members to interact in a search for satisfactory relationships. Although a great variety of interpersonal needs can be identified, the research and observations of several investigators (reviewed in Haythorn *et al.*, 1966) emphasize the importance of three needs which are generally found to be statistically independent. These are the needs for (a) affiliation, (b) dominance, and (c) achievement. With regard to any pair of individuals, individual needs for affiliation may be congruent or incongruent, needs for dominance complementary or competitive, and needs for achievement congruent or incongruent. The nature of these interpersonal need relationships have been shown to be related to emotional symptomatology and stress in isolation (Haythorn *et al.*, 1966), the social withdrawal and territoriality behavior described above (Altman and Haythorn, 1967a), and crew performance on a variety of tasks (Altman and Haythorn, 1967b).

It has been argued that interpersonal need relationships that are competitive, noncomplementary, or incongruent can produce interpersonal stress, defined as perceived interpersonal relationships capable of producing escape and avoidance behavior. Self-reports of subjective stress, the pattern of social withdrawal from each other, the increased territoriality behavior, and the higher frequency of requests for early release from experimental conditions by pairs of men with such incongruent, noncomplementary, or competitive needs lend support to the supposition that these relationships are indeed stress-inducing.

Competitive needs for dominance are seen in isolated dyads (two-person interactions) to generate "fight or flight" tendencies, evidenced both by high levels of interpersonal hostility and relatively high frequencies of aborted missions. Such aborts, however, would be out of the question in a long-duration space mission, as they are in Antarctica. Since fleeing is impossible and fighting is dangerous, suppression of hostilities would seem to be the most likely form of adaptation. This is hypothesized by both Rohrer (1961) and Mullin (1959) to be one of the main sources of psychosomatic ailments in Antarctica, as mentioned above. Both social withdrawal and territoriality behavior have been seen in laboratory settings as stress-management mechanisms. Social disengagement and encapsulation, while possibly effective for short-term interpersonal adaptation, seem unlikely to be effective on a long-duration mission without simultaneously incurring severe decrements in morale, activation levels, and orientation to reality.

COMPATIBILITY, COHESIVENESS, AND CREW COMPOSITION

A fair amount of research has been conducted on group composition and compatibility (*cf.*, Haythorn, 1968). A review of this research suggests that group compatibility is a comprehensive concept that includes a variety of interpersonal relationships. These include: (a) need complementarity, defined as the state of affairs existing when two individuals have differing needs that complement each other, as for example when one has a high need for dominance and the other has a high need for submissiveness or when one has a high need for nurturance and the other a high need for succorance; (b) need congruence, characterized by two individuals having similar needs that are mutually satisfied in the same interpersonal relationship, as when both have a high need for affiliation or both have a high need for autonomy; (c) skill complementarity, existing when the inabilities of one individual are compensated for by the strengths of the other and vice versa, as when a skilled pilot and a skilled navigator work together to form an effective team; (d) cognitive complementarity, existing when two individuals have nonoverlapping knowledge of interest to both of them, such that each can learn from the other or rely on the other for cognitive resources; and (e) value homogeneity, wherein two or more individuals share a common value system, belief system, or code of conduct. All these various kinds of compatibility relate to group viability, but in different ways and with different implications when missing.

Any social system relies on bonds of attachment among its members. Broadly speaking, "cohesiveness" is a term used to designate this quality, sometimes referred to as "unity" or "solidarity." As these terms suggest, members of cohesive groups are more inclined to stick together and to engage in cooperative interactions. More to the point, they are also more likely to function effectively in reaching common goals. The extensive research literature on cohesiveness shows that it embodies two sources of individual attraction to the group. Hagstrom and Selvin (1965) have labeled these "sociometric cohesion" and "social satisfaction." The former reflects the element of interpersonal attraction within the group, and the latter those attractions provided by the group's main activities.

On a long-term mission of the kind envisaged, we may assume that participants would be highly selected and strongly attached to the technical side of the mission. What might vary more would be the positive feelings they had toward one another, in terms of compatibility. Such feelings, over the length of the mission, would undoubtedly take on greater weight as a source of rewards. One obvious implication of the consideration that personal attachments will be increasingly important as a feature of cohesiveness is that crew members should be selected with this in mind. Insofar as possible, they should be given ample opportunity to come to know one another well in advance of the mission and to be able to have a voice in determining whom they wish to have along on the mission. This presents a sensitive problem, given the delicacy of introducing sociometric measures which might seem to some to be a "popularity contest." Nevertheless, a considerable amount of research sustains the point that sociometric ratings can be useful data for predicting later performance, including interpersonal relations (*cf.*, Hollander, 1965). Such ratings have also been found to relate to the total effectiveness of groups (e.g., Havron *et al.*, 1951). The value that team members place on one another could be made more than simply a matter of liking; it could readily embody a judgment about each person's contribution to the total mission.

PROCESSES INVOLVED IN GROUP DEVELOPMENT AND STABILIZATION

In the early phases of group forming, individuals must orient to each other and get acquainted. This acquaintance or "social-penetration" process has been studied by Altman and Haythorn (1965), Taylor (1968), Taylor and Altman (1966), and Taylor *et al.* (1969). In general, individuals exchange information in a more or less orderly fashion, revealing relatively superficial information initially and progressively revealing ever more intimate information. In isolation, this social penetration process is accelerated, frequently resulting in individuals becoming threatened by being "overexposed" to each other: personal information is perceived as being capable of being used against one. That is, to reveal an item of personal information about oneself to another provides the other with a degree of power over the revealer. According to Taylor *et al.* (1969), the process proceeds in a *quid pro quo* fashion, with one individual revealing information about himself, then waiting for comparably intimate information about the other person. In a long-duration flight, however, it seems likely that crew members would be rather well acquainted before the beginning of the mission and that only the most intimate information would remain for interpersonal exchange during the mission. The degree to which information will already have been exchanged prior to the mission will undoubtedly affect the rate at which individuals exhaust each other as sources of stimuli, but a high degree of prior interpersonal exchange would also minimize the likelihood of discovering severe degrees of incompatibility after launch.

Likewise, it seems probable that prior to the mission a high degree of value homogeneity will have been achieved by crew members, either through having come through a similar selection process or through having extensive preflight interaction. Small-group laboratory studies indicate that the degree to which value homogeneity has not been achieved will be related to the initial pattern of communication developing within the group and to the ultimate constellation of interpersonal relationships that develop. Schachter (1951) found, for example, that the more deviant members were the targets of more frequent communication initially but were ultimately rejected if they persisted in their deviancy. Social psychological research on college students indicates more often than not that conforming to majority opinion is the adaptation mechanism of choice for such subjects. Whether or not this would be the case with the type of men selected as astronauts seems very much open to question. Such individuals will undoubtedly have a high degree of self-esteem initially, based on a long history of success accompanied by positive reinforcements. The strong ego developed by such a reinforcement schedule is not likely to yield cherished values and opinions readily. As pointed out by Radloff (1961), individuals who are uncertain about the correctness of their opinions are likely to seek affiliation with other people in order to evaluate those opinions via social comparison. Conversely, individuals with a high degree of self-confidence would be less likely to evaluate the opinions of others as superior to their own. From these observations it seems reasonable to expect that individuals with strong egos, as astronauts are likely to be, will be less able to adapt to each other through the mechanism of developing shared values and opinions than would individuals with less self-confidence.

They might also be expected to be more tolerant of differences of opinions, but whether this would result in increased stimulation through lively discussions or the withdrawal and encapsulation adjustment is impossible to determine at the present time. In the only long-term study of astronaut types known, the Soviets confined three men to a space cabin simulator for a year, terminating in November 1968. The only reports available to the scientific community at the time of writing are releases to the press (*Izvestiya, Pravda,* and *Trud*), which made frequent reference to the importance of crew compatibility. These references are difficult to evaluate but would seem to suggest that differences of opinions were not uncommon among the group and were apparently significant enough to attract the attention of the investigators conducting the study.

Even though astronauts are likely to be men having great self-esteem and ego strength, it is still probable that they will be faced with unusually strong pressures toward in-group uniformity. These pressures are demonstrably stronger when groups are homogeneous rather than heterogeneous; cohesive as opposed to incohesive; in groups of acquaintances rather than strangers; in groups composed of talented individuals; in groups whose members are dependent on each other for the achievement of goals; when the individual is fearful or under stress; on issues relevant to group goals; and on issues irrelevant to other groups of which the individual is a member. On all of these variables, it would seem, the spaceship crew would be expected to experience pressures to uniformity of values, opinions, behavioral expectations, and codes of conduct.

Considerable social-psychological theory and research has been directed to the processes of social comparison and social reality-testing (see, for example, Festinger, 1954; Radloff, 1966; and Radloff and Bard, 1966).It seems clear that individuals use each other to determine the validity of their opinions, the appropriateness of their emotional reactions, and the adequacy of their performance, particularly when these are difficult to determine objectively. In the confines of a space vehicle, opportunities for objective reality-testing may be severely limited, since the variety of objective experiences would be confined to possibilities determined by the physical characteristics and objects contained in the capsule miniworld. This should increase the relative importance of social comparison and social reality-testing in the individual's attempt to orient to reality. To the extent that previously discussed difficulties impair these processes through reducing the degree of interpersonal communication, problems could perhaps be expected in the crew members' abilities to maintain realistic, accurate, and stable self-concepts.

The development and stabilization of effective system performance will presumably have been achieved prior to launch and during training. This will have involved the development of complementary role relationships, a command structure recognized by all crew members as legitimate, a well-exercised and effective communication pattern among crew members for interdependent crew activities, and the development of crew operating procedures unique to the crew and its mission. It would be a mistake to assume, however, that this stabilization once achieved would be forever constant. The perceptions of individual crew members are likely to change over time, and this could change the perceived legitimacy and meaningfulness of the crew structure existing at time of launch. The tendency of isolated groups to restructure themselves from the initial official leadership hierarchy to one that is more determined by members' individual capabilities and personalities has been occasionally observed and reported anecdotally. Individuals may perhaps perceive themselves aging, deprived of normal psychological and social growth experiences. The meaningfulness of the mission to individual crew members may not remain constant over time. Unchanging environmental parameters will undoubtedly be progressively less stimulating. The EEG alpha rhythm changes mentioned earlier may proceed, with concomitant changes in arousal level, stimulus-seeking behavior, interaction rates, etc. Since no long-term research has been addressed to these problems, they are difficult to evaluate. Therefore, it seems mandatory that progressively longer laboratory studies and orbital flights should make provisions for collecting data on these kinds of adaptation phenomena.

CONCLUSIONS

No attempt has been made in the foregoing to review all the relevant literature exhaustively. Many of the references are themselves review articles which cover in more detail the nature of the research data bearing on the phenomena herein discussed. Generalizing from the available literature to the conditions of a long-duration manned spaceflight, such as an interplanetary probe, involves a great deal of uncertainty, since none of the reported research represents all the conditions of such a flight validly. In particular, the durations that have been studied have been much shorter than the one- or two-year space mission; none has used as subjects men drawn from the same population from which astronauts are selected; and obviously none has involved the degree of physical separation from earth that long-duration spaceflight entails. It is therefore impossible to draw conclusions with any degree of known confidence. Nonetheless, the observations and research that have been reported and the field studies such as Sealab and Tektite which are perhaps the earthbound missions closest to spaceflight (e.g., McGrath, 1970; Radloff and Helmreich, 1968; Haythorn, 1967) suggest a number of problem areas that deserve further and continuing attention.

It seems that the long-term viability of the human group under such conditions will be intimately related to the personality composition of the crew at the outset, the degree to which a challenging task and meaningful variety of stimuli can be provided, and the effectiveness with which procedures can be designed to maintain interdependent activity on the part of crew members directed toward superordinate goals.

A program of continuing empirical research and theoretical attention to the higher-level needs of man in such a miniworld should be developed and maintained. This requires a model of man that transcends the biological and individual psychological models prevalent in the life sciences and psychology. Since the unit of concern here is the total system and its performance, a model of man emphasizing the interdependencies between and among group members in a physical situation seems required. An attempt to decompose such a system is presented in Table 1. The columns represent human needs, according to the hierarchical taxonomy advanced by Maslow (1943). The rows represent sources of satisfaction or frustration for those needs. Each cell, then, represents phenomena associated with the satisfaction or frustration of that particular need by that particular source. No claim is made here for the exhaustiveness of the entries in the cells of the matrix. Rather, the matrix is proposed as a way of looking at the man–environment interaction, attending to the differential needs of man as they interact with different aspects of the social and physical environment. A cell-by-cell discussion of the matrix would perhaps be premature at this point, but it is hoped that it will provide a framework for further elaboration in the future. It is not premature to note, however, that the cells of the matrix receiving the most attention up to this point have been those concerned with physiological needs and safety, particularly as these are affected by the individual characteristics of the astronauts, the responsibilities of the embedding organization (NASA), and the design of the spacecraft. Much less attention has been paid to the higher-level needs or to the role of other crew members and the ground crew as sources of satisfaction or frustration.

RECOMMENDATIONS

1. It is strongly recommended that research be undertaken to identify and model personal, interpersonal, and superordinate needs and goals within the context of the miniworld of the spacecraft and its microsociety. Higher-level needs and additional sources of needs satisfaction should be more intensively examined for the relevance they

TABLE 1 Human Needs and Sources of Their Satisfaction: A Man–Environment Relationship

Sources of Satisfaction or Frustration	Human Needs						
	A. Physiological	B. Safety and Security	C. Affection	D. Esteem	E. Self-actualization	F. Cognitive	G. Aesthetic
1. Self	Stimulus needs Activity preferences Territorial needs Life-support needs Sleep patterns	Trait-anxiety Isolation tolerance Effectiveness of coping with primary process Baseline excretion of adrenalin	Need for affection	Need for esteem Need for dominance	Need for achievement Self-concept Total personality	Cognitive needs	Aesthetic needs
2. Other crew crew members	Life-support interdependency Stimulus value thereof Interaction preferences	Agressiveness of partners Overexposure Leadership	Congruence of affective needs	Complementarity of needs for dominance and esteem	Congruence of achievement needs and values Over-all complementarity of personalities Role complementarity Compatibility of roles with personalities	Cognitive stimulation Complementarity of knowledge Congruence of cognitive interests	Congruence interests Aesthetic stimulation

3. Embedding organization (Larger social system	Outside Expectations provided	Rescue possibilities Intervention possibilites Provision of safeguards Expressed concern for safety Emergency procedures training	Supportive communication Availability as scapegoat	Recognition afforded Group structure established	Role assignment Crew composition process Role definition and reinforcement Feedback regarding value of role Cultural context of mission	Provision of sources of information Responsiveness to informational inquiries	Provision of aesthetic opportunities
4. Physical environment	Life-support system Recreational facilities Stimulus variety Mission duration Space available	Physical danger Built-in safety Opportunities for privacy	Group size	Status symbols in living–working space	Variety of activities permitted Physicocosmic context of mission	Sources of information	Richness, beauty of environment

may have for successful mission accomplishment, and research methods and measurements for their further study should be developed and applied.

2. Once needs are identified and appraised, ways must be found to satisfy or alleviate them. If suitable long-term sources of needs satisfaction would not be intrinsically available in the spacecraft microsociety, additional substitute or compensatory measures should be initiated. Research should include identification and implementation of meaningful tasks and goals within the framework of spaceship operations that would allay, prevent, or possibly override conflicts and incompatibilities arising from personal and interpersonal needs.

3. Astronauts' preflight training should include education into the nature of personal, interpersonal, and group superordinate needs and goals; ways to recognize symptoms of social distress and conflict in oneself and others; and ways to correct, combat, or compensate for deficiencies.

4. There is a great surfeit of substantive research questions demanding attention. Among the more important of those that bear on the subject of this chapter are (a) what the sources are of the central-nervous-system changes noted in prolonged periods of comparative monotony; (b) how far the apparent deactivation and de-arousal process progresses, and what its behavioral and psychological concomitants may be; (c) what role various aspects of interpersonal compatibility play in mitigating the process of social withdrawal and encapsulation noted in several studies; (d) the role of leadership in maintaining adjustive interpersonal relationships; (e) the dynamics of attributing discomfort to other people, physical circumstances, or intraindividual processes; (f) the effect of training on long-term adaptation; and (g) the techniques of environmental and group restructuring that are most effective in maximizing long-term group viability.

9 A Social System Approach to Long-Duration Missions

The complexity of space operations is conceptually no greater than that of many other technologically advanced programs in modern society, but in actuality it presents more difficult problems because of the unusual character of the space environment. In the case of missions lasting a year or longer, the order of complexity is magnified in almost every aspect. For planners of such missions, it is essential not only that adequate information be available with reference to all relevant factors of crew, vehicle, technological systems, environment, procedures, organization, and mission profile, but that the implications of interrelationships among all of these be well enough understood to maximize the effectiveness of decisions that require expertise in more than one discipline.

Aerospace engineers, physical scientists, medical and biological scientists, psychologists, and other specialists need a common frame of reference in which they can view their mutual problems. Such a frame of reference views the complex microsociety of the spaceship, comprising the ship itself, its crew, the environments in which it travels, its relations to the organization and society on which

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it depends, and all other aspects as a *social system*. It is believed that the social-system formulation provides the most viable framework for achieving systematic, consistent, and logically interrelated decisions in the planning and operation of long-duration space missions.

The implications of extended mission duration for interpersonal interaction, work, and living arrangements during long periods of severe space restriction, enforced intimacy, and social isolation have been widely recognized as focal aspects of the general problem. However, associated with these, it is necessary to anticipate other changes, not all of which can be identified at this time. For example, it appears likely that substantial extension of mission duration will result in significant changes in crew composition and individual characteristics. It is certain that longer duration of missions will require technological changes in power sources, life-support systems, communication, sanitation, and recreational facilities. The best-educated speculations on all these factors must be taken into account in evaluating their possible implications for future missions.

Although it might be of interest to attempt to start from scratch and prescribe every element of the social system for the long-duration mission, it is practically more appropriate to approach the problem in terms of the changes required in the transition from the successful short-term, three-man, Apollo system. In this context, it is apparent that the changes are confined principally to certain personnel and organizational aspects and that in most major respects the long-duration system reflects the same constraints imposed by space environment and technology as the earlier, short-term system. In addition, the obvious advantages of building on successful past experience should be exploited as far as possible.

THE SOCIAL-SYSTEM CONCEPT

The concept of a group or organization as a social system is not new (von Bertalanffy, 1955; Boulding, 1956; Miller, 1955; Ashby, 1958; Rapoport, 1956; Berrien, 1968; Katz and Kahn, 1966). In essence, it expresses the organization and functioning of an organization as an integrated and interacting unity in which all components function in interdependence with all others and in which relationships within the organization and environment are aspects of the whole. The inherent internal consistency of a perfect system gives rise to the *principle of system congruence*, which requires that all parts be compatible and mutually reinforcing. This principle underlies the following exposition. The model presented here was developed in 1966 (Sells, 1966) and elaborated in subsequent papers (Sells, 1967, 1968, 1969; Sells and Rawls, 1969; and Gunderson, 1970). It is frankly a structural model, focusing on such factors as group size, membership composition, organization, types of goals, sites of activity, equipment, skills, authority, and other dimensions that characterize distinctive human social situations. This model does not include categories to describe system operations, such as the behavior patterns involved in leadership, management, and decision-making. Some constraints of structure have predictable effects on function. However, the specification of system functions (operations) for complex man–machine social systems remains as a next step in the development of a complete model.

The system description involves eight categories, discussed below, that have general relevance. These are objectives and goals, philosophy and value systems, personnel composition, organization, technology, physical environment, cultural–social environment, and temporal characteristics. Each of these categories involves factors that can be ordered or scaled for comparative analysis. The generalized model contains many factors, appropriate for taxonomic analysis, that can be dropped because of lack of variation where the model is applied within the framework of a specific culture group. This will be most apparent in reading the factors listed under cultural environment.

OBJECTIVES AND GOALS

In the context of the microsociety of the long-duration space mission, goals are viewed as critical elements of system structure rather than in terms of specific task objectives. (The latter are treated in other sections of this chapter.) To permit intensive analysis of this microsociety, as well as to distinguish it from other microsocieties in which varying types and degrees of isolation, confinement, and stress are common features, the following seven variables particularly relevant to space mission goals are proposed: degree to which goals are formally prescribed, degree to which goals are mandatory or discretionary, endorsement of goals by formal authority, degree of goal polarization, degree of remoteness of goals, clarity of success criteria, and degree of uncertainty of success (risk).

In addition, at least four other characteristics of goals relevant to isolated microsocieties should be added to achieve generality: unitary versus multiple goals, degree of competition with other organizations, emphasis on growth, and whether the activity is planned or unplanned.

Objectives for space missions are formally prescribed to a high degree. These objectives may be reviewed from time to time by officials of the space agency, and crew members may participate in such review, but when the mission begins, objectives would be mandatory and discretionary changes minimal.

Aspects of social-system goals relating to the degree of formal structure, whether goals are mandatory or voluntary, and the nature of the authority under which they exist are more properly treated under Organization.

Polarization reflects the extent to which an organization is goal-oriented with respect to one or more major goals of importance to its sponsors and members. The space organization was initially highly polarized in both programs and projects, with clearly defined, publicly announced goals and with resulting high morale. The consequences of delay in formulating and announcing post-Apollo goals have yet to be evaluated fully, but some negative effects on morale are already visible. For any given flight program, however, polarization is high.

Remoteness refers to the time between initiation of an activity and attainment of its goal. As the space program progresses, remoteness of some goals decreases. On the other hand, as the duration of individual missions increases, the particular goals of those missions become more remote. Remoteness of goals would appear to be a major problem in long-duration missions. To maintain group integrity and motivation of group members, the void between initiation of a mission and final attainment of its goals must be filled with richly detailed programs of activities that permit achievement of meaningful interim goals. It is also important that both the ultimate and intermediate goals be expressed in a manner that permits assessment of success in a way that is compatible with supervisory controls, available rewards, and individual and career growth. These problems need to be viewed in a perspective different from that of the past when astronauts typically received a telephone call from the President, were promoted, and soon thereafter left the program.

Criteria of success in goal attainment may vary from confusion and ambiguity, in the case of certain types of organizational goals, to clearly defined, measurable events or dimensions. Space-mission goals have generally involved specific, measurable criteria, but there has been some ambiguity in assignment of credit. It has appeared, at least in the public press, that a greater share of credit is due to the planners and directors whose training and guidance were followed so skillfully by the astronauts in flight. The emergence of the backup organization as a hitherto neglected factor in mission performance was highlighted in the Apollo 13 mission.

An important consideration in any group enterprise involves the degree of *uncertainty of mission success,* both objectively and as perceived by the participants, and the objectives and perceived consequences of failure. Despite the phenomenally successful record of U.S. manned spaceflights to date, they may all be objectively characterized as involving high risk. The superb planning, provision of backup systems, testing, training, and over-all preparation for successive missions undoubtedly reduced subjective risk and increased confidence in the Mercury, Gemini, and Apollo programs. Yet the experience of Apollo 13 will not soon be forgotten, and it will be a long time before the apparent complacency that existed prior to this mission (at least on the surface) is restored. New programs will entail new hazards, and both objective and subjective uncertainty may be expected to fluctuate as new programs, and the missions within the programs, are activated. Shifts from mission to mission in the degree of uncertainty about success can always be expected to have implications for recruiting and motivation, as well as for administrative, legislative, and public support.

When isolation is entered knowledgeably, with purposeful planning, preparation, training, and appropriate equipment, the likelihood of successful outcomes is greater than with unplanned, upprepared, or accidental experiences. Even in the cases of wartime bombing of cities and natural disasters, advance knowledge of possible occurrences and of procedures to follow has materially reduced casualties.

With regard to *multiplicity of goals,* it is essential that all major objectives be clearly enunciated because of their implications for organizational structure, staffing, and system operations. Scientists' objectives, role relations, and modes of participation would need particularly careful delineation.

If degrees of *competition* with other organizations and emphasis on *growth* are high, special attention must be given to public support and funding.

In considering possible changes required for transition from the successful short-term, three-man Apollo system to the long-term mission with possibly a larger crew, no differences in formal system characteristics appear to be indicated. Increased remoteness of goals and less certainty of success raise questions concerning management of the long-term motivations of crew members and maintenance of the needed support of the government and the public. Problems may occur on how to sustain interest in a long-duration mission when the only news over long periods may be changes in location. Possibilities of scientific programs by television and regular communications from space may be relevant.

There is a problem concerning definition of criteria of success, particularly in relation to intermediate goals. This may well be crucial to the approaches to the questions raised above.

PHILOSOPHY AND VALUE SYSTEMS

The philosophy and value systems of an organization generally reflect the attitudes of its governing center with respect to ethics, concern for human values, designation of priorities in decision-making, and other fundamental policies critical to system operation. Whether formal or informal, every group or organization is guided by some governing value system, which may range in acceptance by members from consensus to conflict, and which may be conspicuous, as in the case of religious institutions, or covert. The following six factors would seem to have particular bearing for long-duration missions: obedience to command, mission emphasis, respect for individual lives, high national priority, military tradition in personnel attitudes, and acceptance of traditional national values.

Although specifically tailored to the long-duration mission analysis, these items have greater generality than may at first glance seem apparent. For example, *obedience to command* is an expression of *control of member behavior by group authority; mission emphasis* reflects the *cost* that the organizational management is willing to incur to assure goal attainment; *respect for individual lives* could be stated more broadly as the *value accorded the individual,* which may include other factors, but in the same general value scale; *national priority* could be broadened in terms of pre-eminence in social esteem; the *military tradition* reflects a set of attitudes regarding acceptance of personal hardships and austerity, masculinity, and patriotism; and similarly, *acceptance of traditional national values* implies conformity with the dominant mores and values of the society.

The aspect of organizational philosophy of most general interest in the present context involves the values accepted with respect to the relative importance attributed to alternative goals and alternative means, costs, and risks related to the attainment of the preferred goals. With the exception of formal religious organizations, the governing value systems are rarely available in documentary form but must be inferred from a variety of sources, such as the record of critical decisions made, key appointments, and speeche .nd directives by key officials. Such a study of NASA and related official values with respect to the space program would be valuable in the context of the present study. In its absence, the following speculations are tentatively proposed.

First, the operations of the U.S. space program appear to continue the tradition of American military aviation with respect to command structure, mission emphasis, respect for individual lives, and cost–risk decisions.

Second, the U.S. Government has until recently given the space program an extremely high priority and has placed virtually all its facilities at the disposal of the space agencies for effective support.

Third, the astronaut value systems appear to reflect those of American military airmen, in character, motivation toward mission, family and personal goals, professional attitudes and identifications, and in the traditions of the American culture with respect to religious, moral, political, and social philosophy (the "American way of life").

Further study is necessary to arrive at a core set of individual, organizational, and national values that would apply to a wide range of organizations. Examples of such value concepts, at the individual level, include the "golden rule"; respect for women, children, and aged persons; competitiveness; the "Protestant ethic"; concepts of fairness, honesty, loyalty, and responsibility and of the "good life"; atitudes toward wealth, power, possessions, comfort, and status.

Many of the values suggested or specified here are interrelated with the items outlined below under Personnel Composition. For some purposes, this overlap might be reduced to distinguish explicitly between values subscribed to by governments and organizations, in their respective formal documents or traditions, and those held by their members, even though covergence is expected in normal experience.

The culture model of the manned space program in the United

States has been almost entirely that of military aviation. Although a few astronauts were recruited from civilian life, most of these received their major relevant experience in military service. The concepts of crew organization and operation carried over from the military tradition have been accepted and understood by personnel throughout the organization and may be regarded as institutionally established. Unless major arguments could be presented, substantial resistance to any proposed changes would be likely. In general, these and broader cultural values identified earlier are not expected to be amenable to change in future missions; for example, integration into the astronaut population of scientists—who often do not identify with the military tradition—has had its problems, and probably will continue to.

PERSONNEL COMPOSITION

Optimal personnel selection tends to be guided by compatibility with goals, values, technology, and other system characteristics. The historical preoccupation of psychologists with individual differences has made the specification of characteristics of members of space crews or other organizations the least difficult to conceptualize of all the tasks in the construction of a social-system model. Unfortunately, implementation is a difficult problem because of the lack of relevant research and the difficulty of simulating situations for research.

A comprehensive list of descriptors of individual crew members involves the following domains of personal characteristics: intellectual level, education, extent of relevant training, extent of relevant experience, personality factors, character and moral traits, physical characteristics, requisite skills, motivation to participate, sex, age, social division or subgroup, and rank.

In addition to the foregoing rather general items, others have special relevance to the microsociety of the spacecraft. These are heterogeneity of personnel characteristics, particularly with reference to noncrew members (scientist passengers); and rank distribution or subgrouping, that is, whether the crew is composed of officer-type personnel only, as in Gemini and Apollo, or of officer and enlisted ranks, as in naval ships and submarines, and whether there is more than one organizational unit in the crew.

Variables in the category of personnel composition might be examined with respect to the upper and lower limits of intellect, education, training, experience, specified personality and moral characteristics, motivation of members to participate, dedication to mission, physical requirements, required skills, age range, sex, marital and parental status, religious background, and the like. This inventory might properly include the entire range of individual differences and demographic characteristics. However, in the present context, it is believed that most of the relevant factors have been enumerated. The well-known bases of astronaut selection have, at least thus far, proved successful, although it is not possible to examine many of the criteria critically. To date, the astronaut group has been drawn, first, from a select group of military test pilots with extensive jet experience and, more recently, from a more heterogeneous group including scientists and engineers. In all cases, intellectual, motivational, emotional maturity, moral, educational, and physical standards have been exceptionally high.

ASTRONAUT SELECTION

The present astronaut corps consists of a group of remarkable men who have attained a unique position of international prestige and influence in the space program as a result of their unparalleled achievements and the circumstances under which they were accomplished. The attributes demonstrated by the astronauts accurately reflect the technological and mission requirements related to the pathfinding, high-risk, high-skill, but short-duration developmental programs that have marked the beginnings of the space era. A group profile of these men would describe them as masculine, aggressive, technically highly skilled, highly educated, experienced military jet and test pilots, men of action, willing to take risks when the odds are reasonable, leaders, decision-makers, and self-confident individualists. Most of these characteristics are needed in long-duration missions, but the active, aggressive, take-charge patterns might be troublesome under the constraints of prolonged confinement and inactivity. Here, attributes of patience, tolerance of inactivity, and sedentary activities would seem essential.

As discussed elsewhere (Sells, 1967), this is a complex and difficult problem because the action-oriented characteristics are compatible with the military test-pilot background, while patience and passivity together with the other required qualifications may be hard to find. However, this is a matter of degree rather than of alternative extremes. The research problems indicated are important. In addition to selection-oriented research involving the dimension of action versus tolerance of passivity in relation to needed background, training, skill, and other pilot characteristics, there are possibilities for conditioning qualified individuals to prolonged confinement that may be worthy of investigation.

Equally important are questions regarding personality and motivational patterns in relation to extended social isolation. Considering the length of absence required from family and other identification figures, the entire domain of recruiting and selection for long-duration missions may require conscientious restudy. Consideration should also be given to problems related to need for privacy, need for personal–emotional support, need for personal space and possessions, and territoriality, as these have implications for crew organization and composition and capsule design as well as individual assessment. Some significant beginnings in the study of these problems have been made by Navy psychologists at San Diego (Gunderson and Nelson, 1963) and at Bethesda (Haythorn and Altman, 1966).

VOLUNTARY VERSUS INVOLUNTARY PARTICIPATION

Tolerance of discomfort, deprivation, and danger are increased when the expected reward is high in relation to psychological costs. Although perhaps not invariable, it is assumed that the reward–cost ratio is highly favorable for voluntary participants and unfavorable for involuntary participants. Voluntary participation is assumed to represent self-initiated inclusion, open choice among equally available alternatives, and informed consent without direct or indirect coercion. Astronauts and aquanauts, as in the Sealab (Radloff and Helmreich, 1968) and Tektite (Radloff, 1969) projects, are examples of voluntary participants in isolation. Monks, nuns, and religious recluses illustrate another voluntary category. Prisoners, shut-ins, entrapped miners, impressed seamen, slaves, and castaways illustrate various forms of involuntary isolation. Inasmuch as the dimension of voluntary–involuntary participation is generally confounded with preparation, preselection, and training, it is extremely difficult to test the position taken on the reward–cost ratio.

CREW COMPOSITION

Crew composition refers to the congruence or compatibility of persons in various roles with one another. The technical skills needed on the long-duration mission must be specified in some detail before crew selection and training can take place. For example, the following roles or functions might illustrate the composition of the crew for a planetary flyby mission: (1) spacecraft commander, (2) life-support systems engineer, (3) physician-biochemist, (4) physicist–astronomer, (5) electronics-communications engineer, and (6) computer-data systems specialist. The last two roles might most readily be combined if space limitations were to restrict crew size to five. The larger crews required for planetary orbiting and landing missions would likely be composed of similar basic roles but perhaps include more scientists from disciplines represented in the mission's principal scientific objective.

Crew selection will likely involve two stages. The first is one of individual screening and evaluation of profiles of technical skills and personality attributes in relation to role requirements; its purpose is to provide a pool of qualified candidates. The second stage is that of crew assembly; the goal is to determine the particular combination of highly qualified candidates that would form the most stable, efficient, and compatible long-term work group. The first stage would draw on the records of experience and achievement of applicants as well as objective measurements of ability, technical knowledge, and personality characteristics. The second stage represents an extremely difficult and, in the present state of knowledge about the determinants of interpersonal compabitility in long-term isolated groups, almost impossible problem on which the highest research priority is needed.

Long-term crew compatibility should be of central concern in crew selection and training. Basic trust and mutual understanding will be put to a severe test in long missions. Some personality-matching techniques for crew assembly were tried out at the Naval Medical Research Institute with short-term laboratory groups and in the Antarctic with long-term natural groups. The results give encouragement to the possibility that sound approaches to this problem may eventually be achieved. Experience with small Antarctic groups under severe conditions indicates that some deterioration in group structure and cohesiveness is to be expected after several months of complete isolation.

The common-sense assumption is often made that provision of the necessary talents and abilities is almost certain assurance of successful group performance. Even when the component abilities are of a very high order, however, group performance over an extended period might well be affected by many factors associated with personalities and social interaction. Thus, interpersonal interaction becomes a potentially important mediating process between member abilities and group performance. Interpersonal attraction or liking appears to be a vital facilitating influence on communication and cooperative behavior in many group studies. While mutual liking, cooperativeness, and high abilities are perhaps not sufficient to ensure effective long-term group performance, it is likely that these conditions together with common purpose, high motivation, and extensive group training are factors that will contribute to a favorable climate for a sustained group effort.

Interpersonal attraction appears to be based largely on similarity in perceptions of the task and situation and of each partner by the other. For certain needs dominance–submission or complementarity rather than similarity might have positive effects. In isolated Antarctic units, group compatibility and accomplishment as perceived by group members after one year was a function of predeployment heterogeneity with respect to recreational interests, autonomy need, achievement need, nurturance and dependency needs, and task motivation (Gunderson, 1968). Altogether, however, very little research has been done on this question. Interpersonal compatibility or mutual attraction and liking deserve serious attention as factors to be reckoned with in crew composition in the context of long-duration isolation, confinement, and social deprivation.

Two questions have been raised (Sells, 1967) that involve the presence in the crew of members whose roles are not completely identified with flight problems. The first relates to the possible need for a personnel-maintenance specialist. If the problems of living and working harmoniously in the capsule society are subjected to strain, ways must be found to manage conflict and reduce interpersonal difficulties. One possibility might be to assign such responsibilities to the physician crew member; another logical candidate might be the commander. These are not the only possibilities, and a solution to this problem may be difficult.

The inclusion of one or more crew members whose roles are primarily that of scientist introduces potential strains from conflicts in roles or goal identification in decision-making. Field reports on the effects of competitive subgroups in Arctic and Antarctic operations emphasize the importance of this issue. At Air Force Aircraft Control & Warning (AC&W) sites in Alaska, Sells (1963) reported that tensions between mission (radar operations) and support (maintenance, supply, and administrative) personnel were a major morale problem.

These problems cannot easily be avoided by covering up. Even if every member of the crew has important functions and none is considered a "passenger," the roles identified as astronaut, scientist, or scientist-astronaut, and the relative status accorded to each of them in informal interaction, may produce strain if they are in conflict. Evaluation of possible alternatives in relation to projected mission goals is needed.

SEX

Admission of women to the space crew at this time would undoubtedly create serious problems in the masculine world of space operations. However, broad trends in the 1960's toward increased penetration of masculine occupations and roles by women may accelerate in the 1970's to a degree that research oriented toward operations in the 1980's might well include objective review of the merits of female participation.

ORGANIZATION

Eleven organizational variables are proposed as particularly relevant to long-duration missions: formal structure, prescribed roles, command structure, centralized authority, chain of command, with provision for succession, backup and support organization, autonomy with respect to goals, prescribed discipline, prescribed social distance among crew, congruence of rank and crew status, and group size.

The overlap among several of these items is obvious, but the extended list serves to emphasize salient facets. It is necessary to examine organizational structure in terms of the degree of formal structure involved, organizational complexity and formal provision for authority, and decision-making and direction (command). These considerations involve centralization of authority, sanctions permitted, provision for succession, chain of command, and the power and role structure. Other factors include autonomy, control of member behavior by the organizational authorities, degree of participation of members in organizational activities, and degree of stratification of ranks or echelons. The question of authority involves formal documents, such as laws and directives, which may specify objectives and goals as well as the limits of authority assigned to various offices and roles.

CREW SIZE

The size and makeup of the crew will depend both on the functions to be performed and constraints imposed by logistic and life-support requirements, including available cabin space. Tentative assumptions about crew size and organization can be made as a framework for discussion. Because of the increasing technological complexity, it seems unlikely that future space crews will number less than three. At the other extreme, the establishment of relatively large bases (10 to 20 men) on the moon and in earth orbit would appear to be technologically feasible in the near future to support expanding lunar exploration and long-range space probes. There probably is an irreducible number of fundamental roles needed to provide all essential technical skills for a planetary flyby mission. The number would appear to be five or six. If one of the basic objectives of the flight were to collect and transmit to earth significant amounts of scientific data, six basic roles (crew positions) would seem to be the minimum. Crew size would tend to increase with the complexity of the mission and with advances in technology, particularly with the advent of high-energy (nuclear) types of propulsion.

Group size is considered to have an important effect on group structure and interpersonal processes, but all its implications are not yet apparent. Some of the ways that group size tends to affect other system characteristics, and the possible implications of these relationships for over-all group functioning, can be described. As group size increases, the number of possible dyadic relations within the group increases according to the formula $(n^2 - n)/2$. Thus a three-man crew would have only three possible dyadic relationships; a six-man crew would have 15 possible pairs, providing a much higher potential for relational complexity than the triad. A five-man group would provide a maximum of 10 dyadic relationships. In terms of discrete patterns of interpersonal relationships within the group as a whole, e.g., with respect to two-way communication channels or mutual affection relationships, the three-man group could have a maximum of only five different patterns, while the six-man group potentially could display several hundred different configurations. In short, the number of potential intragroup relations multiplies with group size.

In assembling crews with diverse technical skills and various kinds of highly specialized knowledge, heterogeneity on many psychological variates would tend to increase with group size. The long-duration space crew would undoubtedly represent one of the most highly differentiated and complex set of technical skills ever assembled in a small group, and the varied occupational specialties included would imply at least a moderate degree of heterogeneity in personal backgrounds, interests, and personality orientations. In general, intragroup conflict may be expected to increase with heterogeneity in attitudes, values, social backgrounds, and cultural interests. A high degree of homogeneity in intellectual and educational levels, motivation, attitudes toward the mission, personal goals, and so on, might be assumed within such a highly selected crew, but sufficient variability to affect long-term interpersonal relationships almost certainly would exist with respect to some of these factors.

The relation of group size to other important dependent variables such as cohesiveness, individual participation, member satisfaction, and conformity has not been studied systematically over a wide range of group sizes and task situations (Thomas and Fink, 1963). In general, small size has been associated with favorable group perceptions. Nevertheless, in one study involving isolated Antarctic groups (Doll and Gunderson, 1969), member perceptions of compatibility and accomplishment were less favorable when the group size ranged from 8 to 11 members as opposed to 20 to 30 members. This was especially true of the military members of the group, who had a less engrossing commitment to a single aspect of the station's mission (scientific project) than did civilian members.

In very small groups, in which only one highly skilled representative of each required technical specialty is present, the individual should experience maximum feelings of usefulness and importance. In larger groups, of perhaps more than eight or nine persons, the addition of new members would make less difference in total group resources, and more redundancy and overlapping of skills would be inevitable. Thus, adding one member to a five-man crew would have much greater significance for system design and patterns of group behavior than adding one member to a ten-man crew. Group size directly affects the relative importance of the individual member and as a consequence has an important influence on participation and personal responsibility. The influence of size on participation is also dependent on the relation of the number of individuals available to participate to the number needed for the activity. Barker and Gump (1964) have shown that when the number available is smaller than the number needed, participation is facilitated; while the opposite effect occurs when the number available exceeds the number needed.

This relationship was also noted by Sells (1963) who found better morale in Alaskan AC&W sites when they were understaffed.

While it is clear that a six-man crew would represent a considerable gain in technical skills over a five-man crew, it is not clear whether the added complexity in interpersonal relations would represent a comparable gain in the realm of social interactions and potential satisfaction. It has been suggested that individuals exhibit a rather limited capacity to utilize available interpersonal relationships. Nevertheless, the gain in over-all richness and complexity of interpersonal relations offered by a six-man as compared with a five-man group might be significant over long periods in an isolated group. The gains in opportunities for interpersonal relationships in larger crews might be offset by some reduction in the importance of the individual.

OTHER ORGANIZATIONAL CONSIDERATIONS

It is important that the principal tasks in each work specialty be carefully defined and that overlap and interdependencies among work roles be determined. Clear definition of the boundaries of task responsibilities and perception of reciprocal work roles would help to prevent confusion, uncertainty, and conflicting role expectations.

Channels of communication underlying efficient organizational structure in small space crews could be studied empirically and simulated. Much higher rates of communication would be expected between similar or interdependent work roles. Because status and autonomy would tend to be high and approximately equal among crew members, communications would tend to be complex, involving persuasion and negotiation rather than transmission along a chain of command.

Concepts and methods are needed for group leaders or managers to monitor group processes, particularly communication patterns, and to diagnose organizational deficienceis early in order to facilitate corrective action in timely fashion. Much incongruity, strain, and conflict can be avoided if the importance of needs for communication and interaction, as well as technical demands, are explicitly recognized from the outset. The complex social patterns that are embedded in any organizational structure can strongly affect achievement of system objectives.

Extremely high levels of technical competence will be represented in the space crew. Long periods of training and preparation will familiarize crew members with the intimate details of equipment operation and maintenance. Yet, full utilization of crew members may be a serious problem on long missions. Meaningful and balanced work schedules for all crew members would be highly desirable and can probably be considered essential for long-term motivation and efficiency. The expectation that steady workloads for all members may be very difficult to maintain presents a challenge to mission planners and designers. Tasks will vary considerably among the highly specialized crew members, and maintenance and repair needs will be unpredictable and possibly minimal. Perceived importance of one's job was observed to be closely associated with self-esteem, satisfaction, and emotional stability in the Antarctic situation, particularly among men with high educational status and high needs for achievement. Because long-term task demands cannot be anticipated accurately, an important function of leadership on the long spaceflight will consist of equitable distribution of work in terms of amount and importance. Allowance must be made for long periods with light workloads and relative passivity of the crew as a whole. To provide crew members with opportunities for participation in open-ended scientific programs would be advantageous. Routine and monotonous monitoring tasks, as well as housekeeping chores, would have to be shared among all crew members but would tend to be unpopular and regarded as "busy work." Furthermore, such tasks would probably account for only a relatively small portion of the total work time.

Although the organizational arrangements for the Mercury, Gemini, and Apollo programs and space crews were generally satisfactory, certain changes may be expected in extended-duration missions as a result of their duration and isolation. The organizational patterns of the Mercury, Gemini, and Apollo programs, with respect to over-all structure as well as crew organization, resemble closely those of military aviation, with much of the command responsibility held by ground command. There has been a tendency for on-board responsibility to increase, and this has been most notable in the Apollo program, although as noted earlier, the experience of Apollo 13 emphasized the importance of ground control. In looking ahead to extended duration efforts, there are grounds for expecting the transfer of much more authority to the spaceship commander. As this transfer develops, problems of ensuring integrity of command in the isolated spaceship may become more acute. This is a major technological challenge for the spacecraft designers as well.

RESEARCH PROBLEMS FOR ORGANIZATIONAL PLANNING

As suggested above, one of the principal changes affecting the social-system structure for future missions in respect to the elements outlined is group size. Although final decisions will involve tradeoffs with many engineering considerations, it is likely that the crews of long-duration missions will range up to numbers requiring organizational differentiation by shifts (watches) and probably by subgroups, with resultant complication of organization relations. The simple triad of the Apollo-class crew will be inadequate as background for planning organizational patterns for crews spending extended periods in isolation. The research problems presented in this area are indeed formidable. The following constitutes a set of such problems proposed by Sells (1967).

Social-System Operations The model as presented here is static, and further development, reflecting transition from structural dimensions to concern with cyclical aspects, changing states, and covariation of elements in different phases should be a high-priority task. It has been suggested that this could begin with formulation of genotypic principles and propositions of functioning social systems.

Research Design and Methodology Caution is indicated in accepting or generalizing from the many data that bear only slight similarity to the spaceflight situation. To the extent possible, the design of empirical studies should take into account the most realistic social-system formulation that can be developed now. Particular attention must be given to questions of how critical aspects of isolation, confinement, and realistic tasks can be simulated and to the use of subjects whose status and involvement in the research tasks are reasonably appropriate. The Tektite and Sealab situations were superior, in this respect, to any others yet observed (Sells, 1969).

Astronaut Selection and Crew Composition A number of important problems relating to selection have been raised. It also appears important to devote serious attention to composing crews whose possibilities for compatibility in capsule society are maximal. In this connection issues of ethnic background, age, and other factors that may not be significant in individual selection may assume new significance. The scientist-astronaut issue has been mentioned.

Authority The authority structure, including the authority of the commander, in areas of living as well as work; the development of a set of "ship's rules" for problem solving, conflict resolution, and as a backup when decision-making guides are needed; the relation of authority "on board" with that "on the ground"—all require extensive study.

Stress Despite concern with stress by many disciplines for many years, the state of knowledge does not permit an "off-the-shelf" approach to predicting and programming the stresses expected in long-duration spaceflight. As indicated in earlier chapters, studies must take account of physiological, social, and interpersonal sources of stress, related not only to parameters of the physical environment and potential dangers but also to separation, frustration, sensitivity to personal habits of associates, deprivation, boredom, inactivity, and health. Analysis of social-system functions and interviews with astronauts and other knowledgeable persons may be valuable in identifying sources of stress and suggesting strategies for mitigation. Creative concern with the design of interior space to maximize privacy; the invention of games; efficient storage of reading materials, movies, and other recreational devices; the programming of work tasks and schedules; and the provision for personal information needs must receive a high priority.

Training and Preparation Is it necessary to "dry-run" a crew for 500 days in order to determine whether it can function for 500 days? Also, how realistic must the preparation be? There appears to be much agreement that the preparation time can be cut, but the entire problem of how to achieve an adequate and effective simulation in preparation for successful long-duration missions merits further critical study.

Motivation How can motivation be sustained over the entire mission? This depends on task structure, role interdependence (mutual reward and reinforcement), and the relation of individual costs and rewards to mission goals.

Privacy, Personal Possessions, Personal Space, and Territoriality More information is required on human needs and particularly needs of astronauts for personal privacy and related behavioral issues. Some research has shown that privacy and personal territory may be significant in socialized management of hostility and incompatibility, but in the spaceship the control of hostility and incompatibility is essential, while the cost of the alternative would be prohibitive. It is necessary not only to investigate this hypothesis but also to ask how privacy needs can be reduced by the composition of the crew; by the reduction of sources of stress, hostility, and incompatibility; by the substitution of rewards; and by other approaches.

Conflict Arousal and Resolution This topic overlaps with others that have been mentioned already but deserves further systematic study in the context of the spaceship social system. The modes of reducing conflict by withdrawal and territoriality, observed both in field and laboratory experience, must be regarded objectively as neurotic manifestations in group behavior and are clearly self-defeating in isolated microsocieties. The review by Rawls *et al.* (1968) showed a great deal of commonality among the concepts of social distance, personal space, interpersonal attraction, conflict, and conflict resolution. These authors cited proficiency in group activities, high membership satisfaction, interpersonal compatibility, ability–esteem congruency, ability–status congruency, and other factors related to increasing mutual attraction as tending to reduce the incidence of conflict. In the group-process domain, they proposed that conflict might be reduced by the development of conditions of mutual interdependence, cooperation and teamwork, decentralization of authority, participation in decision-making, mutual trust, open lines of communication, free discussion and feedback, socially approved modes of expressing hostility, and supportive leadership.

Communication Should crew members receive personal information of a stressful nature in flight or should such information be censored? The alternatives are both undesirable. How can crew members be prepared to receive and adjust to information concerning death of loved ones, notice of divorce, or similarly stressful events? The entire question of information in and out, in terms of logistics, psychological effects, and methods of control, is another critical issue.

Individual versus Group The evidence indicates that individuals tolerate isolation and other stresses better as members of organized groups than alone. The influence of the group is undoubtedly mediated by group structure and dynamics (including acceptance of role expectations and requirements, reciprocal role relations, leadership, discipline, and mutual support) characteristic of military units, space and ships' crews, and organized expeditions. The disorganization and panic often observed in civilian disasters refelcts the reaction of unorganized collective aggregations rather than of organized groups.

TECHNOLOGY

Long-duration manned missions will employ technologies that may now be only in the planning stage. In conceptualizing the tasks, equipment, quarters, and other aspects of the spaceship social system, it is essential that planners take into consideration the effects of possible new propellants, new means of communication, improved life-support systems, and the like. Seven system characteristics related to technology are proposed. These are degree of technological complexity, relation to the aviation tradition, use of simulators and other technical training devices, degree of preparation for missions, use of technical communication procedures, physical preconditioning, and scientific principles involved in operations.

It is almost meaningless to discuss such things as personnel and organizational behavior without taking account of the nature, complexity, characteristic operations, and traditions implied by the technology involved. The technology not only makes distinctions, such as between jet aviation and the earlier piston–propeller era, which involve differences in speeds, altitudes, schedules, and payload, but also between personnel types, traditions, training, and other significant factors associated with the respective technological fields. The technology of spaceflight is still developing, although it follows the aerospace tradition. Among the peculiar aspects are the overwhelming significance of intensive training in anticipated emergencies as a means of ensuring reliability of performance; the high level of training, experience, and skill required of crew members; the glamour associated with astronaut status (which has reached new highs with the Apollo program); and the high risk associated with the very masculine (in the United States) astronaut role. The space technology has created new specialties and new vocabulary and technical jargon and is regarded as one of the frontiers of human advancement. The type and extent of training and preconditioning provided participants are factors closely dependent on technical complexity.

At any given time, technology may represent constraints to be accepted rather than variables to be studied, except to the extent that one has available tradeoffs that are not precluded by cost priorities (values). At all times, technological complexity depends partially on costs and available resources. Whether or not better foods, more space, or the like, become realities, technology looms first in planning considerations and should be thought of as it will exist in the future rather than at present.

In terms of internal congruence of the social system, technology always has direct implications not only for personnel requirements but for the traditions and values represented by the occupational specialties concerned (for example, the test-pilot subculture). Changing technologies may result in subtle social-system changes that need to be sought and evaluated; for example, shifting from an emphasis on electrical engineering to automated electronic systems might reduce reliance on on-board navigational skills or on-board maintenance of communications systems. In any event, each new technological development may have specific implications for safety, comfort, communication, and recreation, as well as for work patterns, that will require careful evaluation. There is every reason to expect that life aboard a spaceship of the 1980's will be vastly different from the "primitive" conditions of the 1960's; to the extent that these developments can be taken into account in long-range planning, even subject to revision periodically, such information should be of vital importance.

PHYSICAL ENVIRONMENT

The rationale for each of the eight physical environment factors listed below should be clear. (The cultural and social environments are discussed in the following separate major category.) The eight factors are personnel protection, maintenance, and life support; remoteness from base; presence of environmental hazards; degree of space restriction and confinement; demands on endurance; static or maneuvering situation; internal and external communication permitted; and embedded environmental stress.

Among the significant characteristics of various social systems are the distinctive features of their microenvironments: these have implications for the level of risk involved and the nature and magnitude of stresses encountered. There are principally two space environments: the space medium, which is unfriendly and hazardous to man, and the spacecraft and equipment, which protect him and provide a supportive environment that enables him to function and endure in space. In extended-duration missions the protective capsule itself may become a major source of social stress with prolonged enforced isolation and confinement, compounded by the period of time during which crew members must share the unnaturally confined quarters as work, living, recreational, and personal space. Mission duration and total dependence on life-support systems compound the threat from hazards encountered in flight.

Several additional facets of the physical environment, which are also related to the technology, involve the distinctions between a maneuvering operation and a static environment, between protracted exposure to embedded but not intrusive stresses and occasional insidious exposure to highly threatening conditions, and between organizations that prepare means of coping with the hazards expected and those that are caught unprepared. It can be stated that the space crew is a maneuvering group, operating in an environmental situation in which it is exposed to embedded but not intrusive stresses over long periods, whose preparations for coping are exceptionally thorough and have been, until now, highly effective.

VOLUME REQUIREMENTS

Space-cabin volume requirements for prolonged missions are as yet imperfectly understood. Plans for space-station vehicles, carrying 4 to 24 men for as long as 13 months, provide for 300 to 700 ft^3 per man. Such projected volumes are based upon rocket booster capabilities, however, rather than on known habitability requirements for particular periods. Fraser (1966) attempted to define tolerance limits for degree of confinement (free cabin space) over short periods of exposure. His analysis of spaceflight and simulation data suggested that confinement of an individual or group in a relatively small space (100–150 ft^3 per man) would result in detectable impairment of functioning within four or five days.

In contrast with that of the Apollo command module, the comparatively large volume of the S-IVB Workshop would appear to provide adequate living space for a crew of five or six, depending on the space requirements for equipment and supplies. Given approximately 700 ft^3 per man for living quarters and recreational areas, proper design could result in relatively spacious, attractive, and comfortable accommodations for short-term occupancy. The adequacy of such accommodations for longer-term exposure would depend upon many factors other than cabin volume per man, as outlined below.

Provisions of individual sleeping compartments and limited storage space for personal property are believed to be an essential requirement for extended missions. Experience in Antarctic groups and other confined situations have indicated that sharing of sleeping quarters and personal space by two individuals over long periods imposes a serious risk of escalating minor interpersonal frictions into major conflicts of unmanageable proportions. Needs for privacy, solitude, and territoriality become accentuated even in short-term confined living and tend to intensify over time.

One guiding principle in cabin design might be the creation of familiar configurations and the simulation of normal earth living insofar as practicable. Another useful principle might be the creation of as many different and distinctive behavior areas or settings as feasible, corresponding to familiar "rooms" in earth habitation. Isolated groups in other settings, such as the Antarctic, go to great lengths to preserve or create semblances of the home culture, including familiar usages of space and symbolic objects. Modular construction of spacecraft interior surfaces (wall, floors, and ceilings), consisting of easily bolted panels, would permit flexibility in the utilization of available space. Space requirements and preferences of crew members could very well change considerably over time, and the possibility of adding, modifying, or rearranging rooms and cubicles would be very advantageous. As food and other supplies are consumed, storage areas could be converted into usable living space.

A smaller model for space-cabin volume and layout is provided by the McDonnell Douglas space-cabin simulator (McDonnell Douglas Astronautics Company, 1969), which is a cylinder 12 ft in diameter and 40 ft in length (4100 ft^3). A 60-day earth-orbiting simulation conducted with a four-man crew revealed a number of minor habitability problems in the initial configuration of living space and life-support equipment. Crowding did not appear to be an important problem for this relatively short period. Food, noise, and restricted water supply proved to be sources of minor annoyance. Improvements in cabin design for the later 90-day test in the same simulator included reduction of noise levels in crew living quarters by grouping life-support equipment and other hardware away from the sleeping area. Maximum free walking space was made possible by careful arrangement of equipment, facilities, and storage areas.

"Confinement" and "isolation" are ambiguous terms. They have many meanings in common usage and usually do not have reference to clearly denoted or standardized environmental conditions, even in experimental studies. In many situations it is difficult to know whether the behavioral effects observed are attributable to isolation and confinement or to other aspects of the total situation.

In the present context it is useful to relate confinement to the volume of free cabin space per man. Free space is that area not occupied by equipment or fixed structures within the cabin. A number of direct consequences of living in a small enclosed space are usually present to some degree; among the most important are enforced interpersonal relations, limited or nonexistent privacy, reduced variety in sensory stimulation, and restricted physical activity. The extent to which these usual accompaniments of confinement can be eliminated or mitigated may have an important bearing upon tolerance of confinement.

The boundaries of the spacecraft environment could be significantly extended by means of extravehicular activity during long missions. Extravehicular activity, because of high energy-costs, might be restricted to essential checking and repair of equipment on the exterior surface of the spacecraft, but even this limited extension of the sphere of movement and activity would represent an important departure from routine confinement.

Human space requirements are not absolute. Norms for individual space have increased historically and are known to vary culturally as a function of industrialization and social affluence. A characteristic human tendency has been for luxuries to become necessities, and this has been true in the case of normal and minimum standards for individual space. In addition to this cultural relativity, many personal and situational factors affect space requirements (Hall, 1966; Sommer, 1969; McGaffey and Trego, 1970). A particularly interesting interaction exists between this factor of space restriction and the preceding one. Restraint and restriction of movement occur in the alone situation. In group situations, the significant aspects of space restrictions include, in proportion to the degree of crowding, loss of privacy and enforced intimacy, as well as restraint and restriction of movement. Although space requirements vary, crowding and confinement to close quarters are significant sources of stress, which increase as a function of duration.

COMMUNICATION

Isolation usually involves the concept of remoteness or distance from civilized society or time required to re-establish physical contact with that society. Psychological isolation in the present context refers to deprivation of social support and social contact and involves the kinds and amount of communication possible with persons outside the space capsule. It can be anticipated that significant amounts of information will be transmitted to and from the spacecraft daily, partly mitigating the effects of extreme remoteness from earth. The information from the spacecraft presumably will consist largely of scientific data and data reflecting the status of spacecraft systems. Much of this information will be gathered by sensors and processed automatically.

It should be possible to transmit news and entertainment on a regular basis from earth for delayed television viewing aboard the spacecraft. Such communication from earth obviously would be of enormous importance in supplying variety in visual and auditory stimulation. Intimate or private personal communications with significant individuals outside the spacecraft might not be practicable, however. This type of deprivation could have important psychological implications for crew members with strong family ties and affectional needs.

The long period away from the earth culture will require consideration of means to facilitate "psychological re-entry." Men isolated in Antarctica for one year sometimes experience anxiety and social disorientation when returned to normal activity.

ISOLATION AND CONFINEMENT

Even with maximum provisions for safety and habitability, the crew would inevitably experience severe deprivation in many areas of personal needs and normal gratifications as a result of the extreme confinement for a long period. Studies at small scientific stations in Antarctica, involving 8 to 30 men, have shown that the probability of irritability and depression, sleep disturbances, boredom, social withdrawal, dissatisfaction, and deterioration in group organization and cohesion varies directly with the degree and length of isolation and confinement. Many other factors are also important; the usual discontinuities in social relationships which permit dissipation or displacement of normal tensions will not be possible in the spacecraft environment, and variety and novelty in interpersonal relations will be nonexistent. While recreational and educational interests and pursuits would assume greater importance in these circumstances, experience in the Antarctic and other isolated situations has shown that the likelihood of individuals initiating such activities tends to decline with long-duration confinement.

Appetite, food acceptability, and adequate nutrition can be expected to represent significant problems during long missions. Weightlessness and low activity levels could have a profound effect upon caloric needs and body mass over long periods. This possibility can be evaluated realistically only by long-term exposure to 0-*g* and confinement conditions. Food and the attractiveness and palatability of food tends to take on added significance in isolated groups, probably because of the absence of other gratifications and the symbolic significance attached to food in the American culture.

Sexual needs have not appeared to create overt problems in long-term Antarctic groups, although the possible contribution of sexual tensions to manifest irritability, sleep disturbances, and related symptoms is difficult to evaluate. Interview reports have suggested lessening fantasy preoccupation with sexual matters over time. Undoubtedly this problem is complex and may depend on work, other stresses, other satisfactions, and the state of physical health, as well as duration of deprivation.

Experimentation on human tolerance limits for various stresses is severely constrained by ethical considerations. Survival limits generally are known only because of accidents. Realistic situations involving long-duration isolation and confinement, therefore, are of prime significance for defining important group adaptation problems and designing experiments to explore substantive hypotheses. Small Antarctic stations represent one such setting. Undersea experiments, such as Sealab and Tektite, with opportunities for continuous observation of behavior under confinement and isolation stress provide important methodological contributions. Laboratory studies of two- and three-man isolated groups at the Naval Medical Research Institute have advanced conceptualization and hypothesis formulation, even though simulation was not attempted.

Subjectively, isolation may involve varying degrees of threat derived from objective assessment of known dangers, as well as fear of the unknown and problems related to separation. In space and undersea operations, the capsule usually exists as a safe shelter in a hostile environment and is protective, as long as it functions adequately, although at the same time its confined internal accommodations may be a source of stress. Threat related to separation will reflect individual differences in personality, status, and personal situations, but the reward component of the reward–cost ratio will also depend on aspects of the mission.

Instrumental versus Obstructive Exposure to Isolation and Confinement Tolerance of isolation is believed to be greater when the isolation is instrumental to an important goal (as in space missions) and reduced when it obstructs goal attainment. Isolation may be involuntary, as in the case of military personnel assigned to remote stations, but better endured when the mission is accepted as plausible, important, and necessary. Involuntary isolation that obstructs personal goal attainment, and for which the goal served is rejected, as in the case of many draftees assigned overseas in Vietnam, is doubly frustrating. Hence the *voluntary* aspect of space crew participation is even more important on long-duration missions than in present ones.

CULTURAL-SOCIAL ENVIRONMENT

The major utility of this aspect of the social-system model in relation to the present problem is that it calls attention to the geographic, linguistic, technological, economic, political, scientific, religious, aesthetic, and social culture that provides a learning context and a cultural frame of reference for the participants in a microsociety and its sponsors.

For any comprehensive analysis, it should be noted that Murdock *et al.* (1961) distinguished 88 significant categories in their *Outline of Cultural Materials.* A modified list of these social–cultural categories adapted from Murdock for a generalized social system model (Sells, 1968) includes language, demography, history and culture change, total culture, communication, records, food quest, animal husbandry, agriculture, food processing, and other categories pertaining to modes of living, industrialization, economy, education, art, religion, organization, stratification, and other important aspects of cultures over the world. Such lists are instructive as a guide to the complexity of the social–cultural environment that may influence organizations and their system characteristics.

The American culture in the 1960's and 1970's has been undergoing rapid transition. Assuming that most crew members for long-duration missions will represent later generations of American youth than the current astronauts, it may be wise to examine trends in cultural norms with respect to significant attitudes and values relevant to participation in space activities and long-range missions in particular. Assessment of cultural changes and cautious predictions of their effects on new personnel entering the program in the future may be as important as comparable efforts, recommended above, to take into account changes expected in technology. Some differences in nutrition, physical standards (height and weight), and education might also be anticipated in later generations of astronauts.

TEMPORAL CHARACTERISTICS

A very important aspect of every social system is its temporal character. Three temporal factors are relevant here. The first relates to the duration of exposure to isolation and confinement in a continuous mission. The second is the total time involved, including preparation and postmission commitments. Finally, the extent to which each daily cycle is fully occupied is important; on a spaceship this is expected to be total, in contrast with work situations while living at home which provide respites from sameness and boredom and many relaxing discontinuities. An effect of the total environment, which may be mitigated to some extent by scheduling and by the provision of opportunities for privacy and solitude, is the magnification of interpersonal stresses generated by the enforced close contacts. As brought out in earlier chapters, the stress of isolation is believed to increase as a function of duration. Long before the voyage of Columbus and many times since, ships' crews functioned effectively in isolation for periods comparable with those currently contemplated for long-duration missions. The critical importance of duration increases, however, as the effects of close confinement and other stresses are compounded for astronauts reared in twentieth-century American culture.

RECOMMENDATIONS

1. A generalized, static, structural model of the long-duration space mission viewed as a social system has been developed to provide a common frame of reference for interdisciplinary planning.

This model should be expanded and refined to take more account of changing conditions (dynamics), covariation of elements in different phases, and specification of system functions (operations) for complex man–machine social systems.

2. Available information on small-group dynamics and individual characteristics is far from adequate to furnish reliable criteria for crew selection and composition in long-duration missions. Broad-gauged, intensive research is called for. Similar information will be necessary to determine optimal organization for the spacecraft microsociety and interactions with new technology and the physical environment.

3. Although the spacecraft is designed to protect and support the crew, it may in time become an added source of stress because of enforced confinement. The dimensions of this problem should be examined in ground-based research using simulations and through inflight experience in order to reduch such stress and provide for some degree of privacy, territoriality, recreation, exercise, and meaningful inflight activities during the long-duration mission.

10 Human Factors and Operational Requirements

The success of the manned space program during its first decade has demonstrated the effectiveness of the operational procedures developed by the National Aeronautics and Space Administration (NASA). Since almost all of the relevant experience about spacecraft operations has been accumulated through this program and is immediately available to NASA, there is little new in the operations area that can be contributed from the outside.

The earlier chapters of this report have reviewed the data relevant to long-duration space missions that are available from laboratory studies and flight reports and have summarized the problems revealed thereby. This chapter will draw upon the earlier sections in an attempt to relate these data to flight operational procedures. After a discussion of General Operational Considerations, which emphasizes the expanded role of crews in the future, the chapter touches on some of the Program Decisions Relevant to Human Factors Requirements to be made in preparation for long-duration missions. There follow sections on Preflight Activities of ground and flight crews, Task Allocation for Flight Activities, and Ground-Based Mission Control Operations. Habitability and Spacecraft Operations are next

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considered and include a discussion of schedules for work, rest, and recreation. Performance Skills on Long-Duration Missions, the following section, deals with retention of skills, research on this problem, and evaluation of flight performance. The chapter concludes with a series of Recommendations.

The nature of the human-factors problems requiring solution for spaceflight operations has undergone an evolution since the early days of manned spaceflight. Initially, such problems as weightlessness raised basic questions regarding the ability of man to survive in space, even for relatively short periods of time. The successful operations of the last decade show that man can survive and perform effectively for three weeks. Future challenges lie not so much in meeting completely novel conditions as in extensions of relatively more mundane problems; these are not atypical of problems that man has faced in many of his explorations of the earth. While questions regarding the long-term physiological effects of weightlessness and radiation remain unanswered, consideration must also be given to the maintenance of health over extended periods of time without access to elaborate medical facilities, to provision for adequate training to handle extremely complex tasks, and to crew selection that takes into account their ability to tolerate long-term isolation and confinement. In considering these issues, the scientist should be in a somewhat better position to provide guidance than when dealing with entirely new and unique situations. Despite this advantage, directly relevant research studies are lacking because data collection in manned missions to date has been limited in order to minimize interference with operational activities.

As indicated in previous chapters, studies indicate that individuals who are isolated and confined have a high probability of showing performance decrements. There is a general tendency to downgrade the importance of these findings because of the significant role of motivation and training in maintaining performance: in the past, the selection of highly motivated pilots, together with a strong focus of national attention on the space program, has ensured that the performance of the astronauts is extremely resistant to impairment by physical stresses. Long-duration spaceflights, however, will almost certainly require significant alterations in the staffing procedures. Individuals with different skills and vocational backgrounds will be required. While a great deal of attention will continue to be focused on the flights, its impact will be substantially reduced in flights of up to two years' duration. Successful performance in the short flights to date does not necessarily indicate that new problems will not arise when significantly different types of individuals must be selected and trained for extended missions. Nor will the relatively more mundane problems of long-duration missions be easily studied. Determination of astronauts' tasks, as, for example, in maintenance activities, will be difficult owing to the complexity of the spacecraft and the long operational periods. Studies of isolation and confinement will be difficult because long-duration experiments are generally precluded by what can be expected of human beings as research subjects.

Several operational considerations, unique to space activities, that affect human-factors planning for long-duration flight must be kept in mind. Because public attention is focused on the program, the man in the system has a greater than "normal" value: what would be acceptable risk in, say, an aircraft development program is not acceptable in the space program. Moreover, loss of a spacecraft crew would be far more damaging to support for spacecraft operations than a similar loss in a military operation or in other less-publicized research and development activities. This feature of the space program is not likely to change. Another feature of the space program is its "cost" to the individual astronaut. Spaceflights are generally few and far between. Long periods are spent in preparation for these flights, and a good portion of an individual's career is built around one or perhaps two missions. Separation from the family is likely to become a major problem in long-duration missions. Individuals selected for the astronaut program must be integrated into the total effort in such a way that they are willing to make a single flight the culmination of a career's effort.

Four elements of the long-duration mission are considered in this chapter: the *ground-support system,* including mission control; the *space vehicle*; the *ground crew*; and the *flight crew.* The roles of each of these elements can only be defined on the basis of an over-all systems analysis. This clearly lies beyond the scope of the present report. Without such an analysis, however, it is not possible fully to describe the crew requirements or the probable effect of long-duration missions upon the crew's ability to perform the tasks assigned to them. This report, then, can only provide an initial indication of the scope of the problems that will require solution.

GENERAL OPERATIONAL CONSIDERATIONS

New hardware will be used in long-duration missions, some of it involving greatly modified systems. These advanced vehicles will be the descendants not only of present-day manned vehicles but of the unmanned spacecraft that have charted the way and perfected the techniques. Another decade or more of manned activity will precede the one- to two-year mission, providing a buildup of tests and experience in flight operations and in man's ability to cope with the space environment. Experience will be gained with special operational configurations to respond to unusual flight conditions and emergencies. All these developments much surely affect human-factors decisions.

The allocation of tasks bears on the total system—spacecraft, ground-support system, flight crew, ground crew. All these components have increased in capability from Mercury to Apollo and, as a result, in size and complexity. As length and intricacy of the mission grows, the tasks assigned to each of the system elements also increase. The emphasis on redundancy results in multiple systems to sense the same quantities and multiple methods to initiate the same operations. As the number of mission operations increases, these new operations are reflected in all four elements: in new hardware for the spacecraft and the mission control center and in new tasks for the ground crew and the astronauts. In a planetary mission, for example, the spacecraft must be designed to operate at a great distance from the earth, where communication delays will make it difficult for the ground to sense emergencies and react with sufficient speed. Since the spacecraft and crew will be on their own, the crew will have to have a complete capability to operate the vehicle. At the same time, operation in failure modes will become more intricate and the impact of any malfunction more serious and difficult to analyze. As a result, the mission control center, with its resources, will become even more significant to crew safety. There is every reason to believe, then, that the tasks assigned to both flight and ground crew will grow and that the number of both flight and ground crew members will increase as a result.

DEFINITION OF A SPACE MISSION

The definition of what comprises a "mission" should also be considered in developing crew tasks. Mission duration has generally been considered synonymous with the flight, i.e., from launch to touchdown, but even in the initial Mercury flights the launch checkout and countdown represented a critical portion of the mission with major impact upon mission success. This characteristic has been magnified by the longer flights and the more complex systems of Gemini and Apollo. In long-duration flights, emphasizing, as they will, the critical role of systems reliability, launch checkout will be an even more extended and more critical portion of the mission. The activities of astronauts and ground crew in this portion of the flight will surely, as they have in Apollo, be highly significant. Thus the astronaut's "task" should include what he does on the ground prior to the launch as well as his activities during the flight itself. The total mission, then, should be considered as that period of time from designation of the crew through the flight itself and finally ending after the postflight period required to debrief and write flight reports. This period of time has increased in the Apollo programs. Crews have been designated a year or more prior to their actual flight. For two-year missions crew designations may (perhaps should) be made as early as two years prior to flight time, and postflight periods will probably last at least 90 days. For the astronauts, then, the over-all mission will encompass four to five years.

EXPANDED PREFLIGHT AND POSTFLIGHT ACTIVITIES OF THE CREW

With the extension of the length of the mission, it is probable that both the inflight and ground roles of the flight crew will also expand. Increasingly in the Gemini and Apollo programs the spacecraft commander's duties have widened. In Apollo, the commander, by virtue of his responsibilities for crew preparedness, has had a major influence on the work of a relatively large group of specialists, including the prime crew and the backup crew as well as the engineers and technicians concerned with preflight training, crew equipment, and flight plans. Similarly, the activities of each of the other crew members now extend beyond the requirements of readying themselves personally for the flight. This trend promises to continue, and by the time long-duration missions are initiated, it is probable that flight crew members will have extensive responsibilities for major portions of the spacecraft systems. As crew members become more responsible for inflight maintenance, they will have to become even more familiar than at present with the engineering details of the spacecraft. Already spacecraft configurations vary from flight to flight as design changes and new modifications are implemented. This tailoring of the spacecraft to the individual mission will become an even more salient feature of the long-duration flight in which the crew will become more and more deeply involved.

The same trend is likely in the case of scientist-astronauts in the crew in terms of responsibility for the scientific equipment on board and a larger role in formulating and conducting experiments: the total length of the mission suggests that it will be less appropriate and less possible for noncrew members to carry the role of a principal scientific investigator. Similarly, crew responsibilities for health maintenance will grow. Certainly if a physician is on board to provide medical care, he will have become familiar with the case histories of the crew and will likely participate in accumulating the baseline data during the two-year period of preflight preparation. As a result he may have a major role in assessing the crew's medical readiness for the flight.

Expansion of the crew's preflight tasks is also desirable from the point of view of over-all crew motivation and commitment. It is similar to the type of responsibility exercised by explorers like Scott and Lindbergh who were not only in command during the actual mission but were responsible for the development and preparation of the expedition vehicle. This identification with the total mission should be particularly helpful in maintaining high morale and alertness during the flight, since crew members will have considerable extra responsibilities and personal investment in the systems with which they are identified.

During the postflight phase, the flight crew should have responsibility for providing information through debriefing and for more direct participation in the preparation of flight reports as well. In this way the crew will have an investment in maintaining good records and vigilance during the flight in order to provide, at the end of the mission, a complete analysis of the vehicle performance in their specialty area.

In sum, inclusion of the crew in mission tasks from initial assignment to the flight through completion of its final report would provide closer identification with the mission and should be encouraged as much as practicable.

PROGRAM DECISIONS RELEVANT TO HUMAN-FACTORS REQUIREMENTS

The concepts described above foreshadow some of the decisions that mission planners must make in coming years in prepration for long-duration missions.

Definition of On-Board Maintenance Philosophy It is clear that malfunctions of the type occurring on Apollo 13 pose a major threat to crew safety. Safe return in the event of system failure will largely depend on the crew's ability to make repairs and modifications. As is well known, there is some conflict between the design principles utilized in systems designed for ease of human maintenance and in those designed for maximum reliability in automatic functioning. In the course of developing the vehicles for long-duration missions, a number of decisions will have to be made in this area. What kinds of maintenance are envisaged? Will all failures be handled by switching to standby units? Will there be modular replacement, or will the astronaut attempt component maintenance? Maintenance philosophy was highlighted by a relatively insignificant but highly visible failure on Apollo 12 in which the television camera failed on the lunar surface and could not be repaired for want of proper tools. It is probable that the amount of inflight maintenance required will greatly increase in long missions, and, as a result, requirements for new crew skills will be generated. The extent of this requirement, however, will flow from basic maintenance design philosophy.

Review and Redefinition of Command and Control Philosophy of Mission Control Center A second major element of operation philosophy requiring definition is the role of the mission control facility relative to flight crew and on-board control. With the increasing complexity of the Apollo and Gemini missions, the capability for on-board control has increased; ground control has had a parallel growth. Owing to the general philosophical emphasis on mission redundancy, both have tended to increase in about equal proportion. Command relationships have been worked out in practice in essential conformity with military aircraft experience. The pattern of growth of both ground and vehicle flight information display and control capability appears likely to continue. In planetary missions, on-board capability cannot be decreased because the spacecraft must operate at such great distances from earth that communication delays may preclude rapid action by the ground control center. On the other hand, the complexity of trajectory information and of spacecraft systems make the development of new operational regimes in response to malfunctions beyond the capability of the limited equipment and manpower on board. Therefore, it appears that the operational requirements for both flight and ground crew will continue to increase and that the command philosophy will remain essentially similar to current practice.

Review and Redefinition of Procedures for Inflight Research A third area of decision relates to scientific investigations associated with the flight. As already noted, the increasing duration of the flights and increasing time of preparation make it desirable that crew members, particularly scientist crew members, have a larger role in the development and conduct of scientific experiments. The current philosophy of having experiments developed primarily by outside scientists, to be placed on board the spacecraft and operated by the crew, may have to yield to a system in which the crew itself is more fully involved. For example, since the long coast periods on interplanetary missions provide an unusual opportunity for scientific investigations and are relatively undemanding in terms of flight operations, it will be desirable to have individuals on board with considerable scientific training. Because of the long period between launch and use of scientific equipment in the region of a planet, much of the effectiveness of the scientific equipment will depend on the crew's ability to maintain it and set it up properly. The interest and dedication of the crew in the scientific experiment will be enhanced if a crew member has an important role in initiating and designing the experiment.

Determination of the Flying-Skill Requirements In the case of planetary missions, the ultimate decisions regarding the landing and maneuvering requirements in the vicinity of the planet will have a significant bearing on the composition of the crew. Men will have been preceded by automatic soft landers; if they indicate that landing is relatively simple, i.e., that it perhaps can be accomplished passively with a parachute, and that launching and maneuvering at the planet do not involve major and new levels of complexity, then the requirements for highly trained pilots on these missions may be reviewed. The probability is, however, that out of a four- or five-man crew, at least two will have flying skills so as to ensure prime and backup capability for critical maneuvers. Even in this case, there should be two, three, or more members of the crew who need not have superb flying skills but who rather would be scientists and persons having considerable knowledge and skill in the maintenance and operation of spacecraft systems. Such crews will probably have different backgrounds and vocations, with the result that the group will be less homogeneous than present crews.

Definition of the Backup Philosophy for the Flight Crew A final element for definition is the backup philosophy for the crew. The Soviets have taken the position that in multiman crews the full crew should be substituted if any member of the prime crew is unable to take part in the flight. In Apollo 13, the United States took the step of substituting a single member of a three-man crew. Last-minute substitutions will be far more difficult and questionable in long-duration missions, however. It will clearly be difficult for an individual to ready himself psychologically as well as physically for a two-year flight in a matter of a few days. To prepare in three days to go away for a week is one thing; to prepare in three days to go away for two years involves an entirely different order of strain upon the family and the crew member. If the capability of substituting either crew or crew members is to be maintained to a period close to launch time, the backup crew will have to be more fully integrated with the prime crew, perhaps through simulation exercises involving a mixture of prime and backup crew members. Prime crew members should be equally effective in working with backup crew members and vice versa. Even so, it seems unlikely that last-minute crew changes will be possible for long-duration missions.

PREFLIGHT ACTIVITIES

As noted in the previous section, the preflight portion of the mission has come to include activities of such central importance to the success of the total mission that it must be considered part of the flight itself. During this period crew members take on responsibilities that go beyond the specific flight tasks assigned to them. At least seven major functions of the preflight program can be defined:

Training for Flight Tasks During the preflight preparation period the specific flight tasks to be carried out by each member of the flight and ground crews are learned. Spacecraft maneuvering and trajectory changes, while complex operations, are relatively easy to provide training for since they are known and can be simulated. It is more difficult to meet the training requirements for the almost infinite number of malfunctions that could occur in flight. This problem will be magnified by the greater complexity of spacecraft and the length of operating time involved in long-duration missions. Even in the Mercury program it was difficult to assure that a good cross section of potential malfunctions was being presented to the astronauts for solution during training, because it was very difficult to determine what malfunctions were most probable. Use of failure-mode analysis techniques assisted in this endeavor, and while flight emergencies have generally not been exactly duplicated on the ground, emergency training has been sufficient to produce good crew response during flights.

Considerable attention will need to be paid to this area in the planetary missions. Not only will the sensing and correction of malfunctions be a major problem, but the crew's task will be complicated by having to work out new mission profiles as a result of these malfunctions. In earth-orbital flights, prompt return to earth is possible in the event of a serious vehicle failure; but the magnitude of the potential problem for a deep-space flight, in which a malfunction may necessitate operation for several months in a special mode, is indicated by the complexity of the new procedures required in the Apollo 13 emergency. The added requirement on the crew to prepare for operation in a modified mode will substantially increase both the time and amount of training.

Opportunity for Crew Familiarization The preflight period also provides an opportunity for flight and ground crews to get to know each other well and to integrate procedures and operations to ensure close crew functioning. If the capability to insert backup crew members is to be preserved, the backup crew will have to be included more in this facet of the preflight training period so that all share the common experience that builds a close intergroup working relationship. Fully as much attention may have to be given to last-minute replacements of a ground crew as to replacements of flight crew because of the major role of the mission control center in the event of emergency. A close feeling of trust is essential to effective functioning of the control center and to the safety of the total mission. More will be said of this in the section on Ground-Based Mission Operations.

Development of Flight Plan The preflight period is also the period during which the flight plan is determined and when alternate and emergency procedures are specified and practiced. The initial flight plans frequently overload the flight crew and are subsequently reduced and made more realistic. Working out flight plans will be more difficult in the case of long-duration missions because it is highly unlikely that the total mission will be simulated in real time or, in all probability, that even a significant portion of it will be simulated in real time. However, changes in flight plan are more probable in the long-duration mission given the increased probability with time of malfunctions. The flight crew must become proficient in modifying flight plans and working out new ones to fit the changing needs of the mission. Therefore emphasis may focus as much on the effects on the flight plan of systems malfunctions and mission changes as on the development of the basic flight plan itself.

Development of Mission Voice and Operational Procedures As already noted, the preflight period is the time in which rapport between flight and ground crew is developed and mission procedures integrated. Emergency procedures, which must be developed anew for every flight, are initially designed by spacecraft engineers and the operations analysis groups and are put in a final form during simulations between the flight crew and the mission control center. It is during such simulations that the flight crew develops confidence in the recommendations of mission control, and mission control in turn develops a familiarity with the crew and its typical manner of reacting.

Development of Scientific Program While the specific experiments for a mission have generally been defined earlier and the equipment developed and qualified, the experiments themselves are inserted into the flight plan during the preflight period and the specific activities involved are practiced in the context of the mission. As suggested earlier, the extended preflight periods will favor development of more of the scientific program at this time by crew members specializing in the relevant fields.

Assurance of Physical Fitness Perhaps the most significant facet of the preflight preparation period relates to the assurance of physical, psychological, and medical readiness. Much of this preparation must be left up to the individual crew member. No major change in current procedures for medical qualification is anticipated in preparation for the longer flights. However, if a physician or medical corpsman is included in the crew, he will wish to become fully familiar, preflight, with the physical status of the other crew members and their special needs and reactions and to begin his case relationship with them well before launch.

Psychological Preparation Each crew member will have to ensure his own psychological readiness for the flight and for the long period of absence from his family. While this absence is not expected to be a major problem, since similar periods of separation have been experienced by military and other families in the past, activities with the family in preparation for the long absence may consume a substantial amount of the astronauts' time during the preflight period.

TASK ALLOCATION FOR FLIGHT ACTIVITIES

Task allocation in manned spaceflight can vary from a spacecraft that requires continued participation by the crew to monitor and operate systems to one that is completely automatic. Similarly, ground control may vary from continuous monitoring and complete control of the spacecraft to one permitting virtual autonomy on board. United States spacecraft have tended to place heavy demands on the crew, while early Soviet spacecraft were nearly automatic. Task allocation has a fundamental effect on crew size and skills, training needs, mission-control requirements, and time available for scientific activities. All these influence crew effectiveness. This section considers the interrelations between task allocation and crew well-being for very long missions.

Engineering and operational expediency necessarily dominated past spacecraft development, and weight, state of the art, and aircraft usage largely determined task allocation. Electronic developments and system characteristics were a forcing function in the assembly of crew tasks. Man many times appeared as a "gap" filler or as a backup for potentially unreliable elements. Test pilots participated directly in design beginning early in Mercury flights, and tasks tended to be designed around test-pilot skills. Tasks placed a premium on continuous control functions and manual override capability where the pilots' highly developed adaptive skills were utilized best. Mercury flights initially were based on a "man-in-the-can" concept, which evolved, after the astronauts entered the program, to a more conventional aviation system with a centerline window and aircraft-type attitude controls and displays. Gemini missions further developed this concept based on the assembly of aircraft-type instrumentation, and the functions of the two-man crew remained nearly conventional despite a 14-day mission. Apollo and the lunar module (LM) brought new instrumentation and capabilities but retained a similar philosophy of tasks.

Characteristics of long-duration missions, however, will necessarily influence present concepts of crew task allocation. On a planetary mission, for example, the cruise phase will be about 100 times longer than the Apollo translunar cruise, ground control and communications will be impaired because of transmission time lags, the crew will have diverse skills, and the spacecraft control and operation workload will be minimal during the cruise phases. These characteristics require a major effort to define the task structure necessary to maintain crew efficiency.

ROLE OF MAN

Man always will have an essential role in spacecraft operations. The issue is whether he can perform this role best aboard the spacecraft or from the ground. Comparative research on manned versus unmanned operations may never be definitive on this point because of the complexity of the issues involved. In any case, the role of man remains an area of controversy and differences. The position taken here is that man will be aboard, and that the major issue is to define the functions that enable him best to earn his keep.

Up to the present time, tasks related to spacecraft operation have predominated because new systems were being evolved and tested. However, there has been a recent upward trend in the proportion of activity devoted to scientific tasks. Now there is an opportunity to take a long-range view. Research can be accomplished in orbital space stations that will help to define better where man's contributions can be maximized for very-long-duration flight. Areas to be considered are crew contributions to: (a) Spacecraft reliability through diagnosis, switching, maintenance, and repair. The pacing item is the two-year planetary mission where greater equipment reliability will be required and return-to-earth capability will be limited or impossible. (b) Spacecraft operations, particularly those related to rendezvous, docking, and landing, where, like landing an aircraft, automation has not been versatile and reliable enough to be completely practical. (c) Scientific research operations, particularly where informed insights can modify experiment protocols. (d) Maintenance of crew health, physical fitness, performance, and morale during long periods of isolation and confinement. Mission length has a direct bearing on man's role as longer durations require more emphasis on his participation in maintaining spacecraft systems and on assignment of tasks that help to maintain his efficiency. Also, much more time is available for research.

It is difficult to define specific tasks now for long-duration missions because the missions themselves are not defined. However, trends can be projected as a basis for defining future functions.

Spacecraft Operations Present crew functions center around launch, staging, re-entry, and landing, with peak activities occurring during operations associated with events such as lunar landing and takeoff, rendezvous and docking, and extravehicular activity. Future missions will probably have long periods in which the only functions related to the spacecraft involve system monitoring and assurance of the reliability of the equipment. As noted above, an on-board capability for system monitoring and tests, repair, and replacement seems necessary. Increased on-board control in maintenance matters would result, and diagnostic and decision-making tasks would be paramount.

Mission Operations On-board tasks relating to the mission's objectives should grow in the future both in variety and in terms of proportion of time devoted to such functions. Astronomical and environmental research, biomedical and behavioral research, and technological experiments are anticipated.

Housekeeping Long-duration missions will increase the need to deal more systematically with the day-to-day processes of maintaining a habitable environment. Food preparation, waste removal, and maintenance of facilities and personal equipment will be demanding because of the limited resources and space available. More specific planning for the maintenance of health and morale will be required.

NEW EMPHASIS REQUIRED FOR LONG-DURATION MISSIONS

Suitable task allocation can improve considerably the tolerability of long-duration flights (Fitts, 1961; Hartman, 1961; Patton, 1966), making the difference between an ordeal and a productive experience. It is suggested that the concepts of job enrichment be applied and social and psychic rewards be deliberately considered. Activities ought to be meaningful and mission-relevant, programmed to have both short- and long-term feedback of results to the crew. Such jobs probably should occupy most of the crews' working time.

If motivational problems should arise, they would be most apt to emerge during the long cruise phase. Tasks characteristic of this phase are envisaged to be systems monitoring; maintenance and repair; communication with earth; housekeeping and maintenance of health; skill maintenance, training, and education; sleep and recreation; and research. Of these, scientific research has the greatest potential for providing continuous and meaningful work during the cruise phase.

Housekeeping is a continuous but potentially dreary activity, and maintenance and repair functions would tend to be sporadic. Research can be rewarding, particularly when provisions are made for on-board analysis, report writing, and even technical presentations to one's earth-bound peers. Where practical, studies can be completed and new ones initiated based on earlier data.

Few directly applicable data exist concerning how tasks, within this context, influence crew stability and organization. The following studies are recommended:

(a) Ground-based and inflight research to define better the influence of task loading, task type, and task structure on a crew's ability to tolerate long-duration flight.

(b) Development of analytical techniques to help assure that task allocation results in meaningful jobs distributed appropriately throughout a mission.

(c) Development of on-board adaptive computer programs to schedule crew activity in a manner that maximizes individual and group motivation in the work.

(d) Development of crew selection procedures which are based on spacecraft and mission tasks rather than on the idea that individuals with a single skill will be cross-trained.

GROUND-BASED MISSION CONTROL OPERATIONS

As suggested earlier, mission control should be considered an integral element of the total flight system, with the ground crew sharing a special relationship with the flight crew. Among the major functions that mission control performs for the flight crew and that are likely to become even more significant in long-duration missions are the following:

Command Function The function of mission command, which is centered at the mission control center, in providing leadership for the flight is not simply centered on its authority over the mission. Although the authority of the flight crew commander will likely increase with distance from earth and length of mission, the leadership role of the control center may also be enhanced by flight duration and the complete isolation of the vehicle. For example, the control center will be the source of all communications with earth—all news, all communication with families. By virtue of its control over the flight crew's contacts with the world, the control center will have a major influence over the crew and its mission whatever the formal command structure.

Another significant leadership function of the control center will be to support and enhance leadership roles among the flight crew and to assist in the definition of responsibilities of the various crew members. Communications from the control center should be handled in such a way that they will help to maintain leadership structures within the flight crew and reinforce individual responsibilities. In this way, the mission control center can help to assure that command authority and motivation are not undermined by the stresses of confinement and can ease transitions of authority within the flight crew should such become necessary.

Backup Malfunction Diagnosis and Fault Isolation The complex systems of the spacecraft will make on-board analysis of malfunctions and failure isolation difficult—impossible in some cases. The availability of a large backup staff on the ground, with extensive computational and engineering facilities, will permit much more detailed analysis than the flight crew can achieve. This role of the control center will be enhanced on long-duration missions because of the greater threat presented by systems malfunction. The importance to the flight crew of this capability, moreover, will increase the authority and leadership of the control center even if further authority is officially delegated to the flight commander.

Development of New Flight Plans The control center's capability for developing new flight plans and new operational modes in the event of malfunction will be critical on long-duration missions. In Apollo 13, an entirely new mission profile and operational system was required in order to make a safe return to the earth. While the general procedures to be followed might have been worked out by the flight crew, the detailed checklist radioed to the vehicle of the actual procedures required were, as the flight crew indicated, beyond their capability to have worked out for themselves. As complex as this procedure was in Apollo 13, an abort mode for a 700-day flight would be far more complex because of the relatively long period of operation in the deficit mode.

Resources in Scientific Analysis The role of mission control in inflight research activities has been increasing throughout the Gemini and Apollo programs. During the Apollo program, research scientists have been present in the control center; they have received direct information from the astronauts and communicated with mission control regarding requests for specific activities during the flights. To date, the duration of activities on the lunar surface has tended to be so short that opportunities to revise plans and redirect astronaut activities from the ground have been limited. It is to be expected, however, that future flights will provide a much greater scope for ground-based participation of this kind in the flight crew's scientific work. The time devoted to such activities would increase, and there should be ample time for interchange between astronauts and ground researchers. In a planetary mission, length of stay on the planetary surface will probably be somewhat longer than that typical of the early lunar landings so that, once again, there will be greater opportunity for interaction between the astronauts and the ground, even considering the greater difficulties in communications. Each landing would be designed to have maximal scientific yield, and direct communications between astronauts conducting field research on the planetary surface and a backup group of scientists in mission control would likely be emphasized.

Another factor leading to greater use of scientists at mission control would be the presence in the crew of a scientist-astronaut. While it might at first appear that there would be a greater need for experienced scientists on the ground to back up nonscientists conducting inflight research, it is probable that the participation of scientists will be more active when scientists are on board the spacecraft. The scientist-astronaut would be more likely to develop hypotheses about the phenomena he is viewing and request literature searches and other background work to test the hypotheses as the experiment is under way. Further, he would find it more valuable to discuss incoming data with his colleagues, using their assistance in making decisions about which materials should receive the most attention on the spot and which should be reserved for postflight analysis. When the investigations must be conducted by relatively untrained individuals, detailed plans must be made preflight and adhered to closely; moreover, it is difficult in such cases to redirect efforts once the flight is in progress. An experienced researcher will feel more confident in departing from the plan. Thus, the role of mission control in scientific backup and consultation will probably increase, even though, or more correctly because, the scientific capability of the flight crew is increased.

Resource for Medical Diagnosis and Consultation Mission control has always played a substantial role in providing medical assistance to flight crews. Flight surgeons are present at mission control and at remote control centers; they not only support the flight crew during countdown and in flight, but between flights serve as "family doctors" to the astronauts and their families. Medical backup is bound to increase in long-duration missions when it will no longer be possible to make all medical decisions on a conservative basis and recall the flight if there are any major concerns. Medical and health problems will have to be dealt with on board. If the medical training of the crew is limited, considerable consultation with ground physicians will be required in order to arrive at a diagnosis and treatment. Even if a physician is on board, he will wish to be able to consult with medical specialists on the ground, just as a scientist-astronaut might make greater use of a ground scientific team. Thus, whatever the final decision regarding crew composition, the role of the mission control in medical and health support will increase significantly in the long-duration missions.

Assistance in Maintenance of Astronaut Morale Another facet of mission control that may be expected to undergo major operational growth relates to personal support of the astronauts. News from earth will be important to the flight crew, not only because of their interest in what is going on but as a relief from the monotony of the mission. Communications will permit inclusion of the ground crew in the psychological life-space of the flight crew. Crew members will not be entirely dependent for all social contacts upon other flight crew members: they should receive considerable social support from the mission control group and, through them, from their families and the world. The potential importance of this kind of support can already be seen by the banter between the capsule communicator on the ground and the flight crew. Even during the short current flights, arrangements have been made for families to talk with crew members and for news to be passed up by the spacecraft communicator. These activities, which are desirable on current flights, may be necessary to crew morale on the long-duration flights and should help to reduce likelihood of the interpersonal conflicts that have been noted in many experimentally confined populations.

While it is probably desirable to provide much of this type of support informally and "on demand" rather than setting a special period for news and personal reports, it should not be left as a completely unprogrammed part of the mission. Considerable attention will need to be devoted to what types of information ought to be available to the crew. Some general decisions will need to be made about the frequency of contacts with family members and the extent to which direct contact will be permitted with individuals other than family members. Direct calls from the President have been a feature of Apollo flights, and, undoubtedly, this kind of assurance of national support will be given from time to time. It would be desirable, however, to provide for a more regular demonstration of the nation's interest and support.

Personal support through communications should be active rather than passive, and interaction between flight crew members and their associates on the ground should be encouraged. Scientist-astronauts aboard the vehicle should have the opportunity to discuss their observations and plans with research scientists on the ground. Engineering specialists, among the crew, could discuss spacecraft systems and new design ideas with their colleagues on the ground. Consideration could be given to regular television broadcasts to the nation by the astronauts discussing the flight's progress and their general observations. Such programs might feature question-and-answer sessions with newsmen or questions submitted by the public. Lectures and other educational activities by the astronauts through educational TV stations are another possibility. Such activities would be likely to enhance public support for NASA and would provide a needed source of contact between the astronaut and the ground. It is recognized that this type of activity has generally been viewed negatively by technical personnel and by the astronauts themselves because of its possible interference with flight activities. On the long-duration missions, however, sufficient time should be available so that such activity, rather than being an interference, would be a support.

As suggested above, the close relationship between the ground crew at mission control center and the flight crew in the space vehicle can act to increase the crew's life-space. If regular interaction is possible with ground-crew members, and if the latter are seen as direct and close participants in the flight, it may be possible to reduce or avoid some of the internal tensions that have been noted in confinement studies. To achieve this result will require particular emphasis upon cooperative exercises during the preflight period of the mission. It is during this preflight period that the close relationships are built up between the flight and ground crews that are conducive to mutual trust and confidence.

Confinement studies show that the crew outside tends to be the recipient of a good deal of hostility engendered by the confined crew. While this type of projection is probably preferable to allowing the tensions to mount up among the confined crew members, it becomes undesirable where a great deal of dependence must be placed by the flight crew on the ground-crew support. If the flight crew can view the ground crew as part of the team, this type of projected hostility should be minimized. A step in this direction was taken from the earliest Mercury missions by assigning the role of spacecraft communicator to an astronaut. This tradition has been maintained and seems very desirable for the long-duration mission. However, the difference between an astronaut voice communicator and other ground-system monitors should begin to disappear, and confidence should be built between the flight crew and the ground crew to the extent that all the senior members of the mission control staff are viewed as fellow crew members.

HABITABILITY AND SPACECRAFT OPERATIONS

The design of working and living space in spacecraft for long-duration missions must provide an environment that allows the crew to perform effectively and evenly throughout a mission: providing only the bare necessities for existence is not sufficient. It appears that this is recognized by planners for future missions, and the following comments are offered in support of this positive approach.

Engineering and operational considerations dominated the design of past spacecraft, and habitability was treated as somewhat of a frill that could be considered later. The result was spacecraft with habitability problems requiring "quick fix" changes after a mission. Most of these problems could have been avoided if habitability had been systematically and deliberately considered during initial design and if a body of technical data had been available upon which to base design. This situation was bearable for short spaceflights, but habitability could be a limiting factor on long-duration manned missions, and design for habitability must be on a par with other major system tradeoffs.

Poor habitability, although an annoyance to the crews, has not seemed to impact their performance on the short missions to date. Military crews have traditionally tolerated uncomfortable crew stations and living quarters for the sake of operational expediency. Perhaps this was justified under some circumstances, but there is a growing body of evidence that men fight (perform) better if their work and living spaces are comfortable, particularly when their missions are long or are repeated frequently. Early B-36's had problems that were solved by later "crew-comfort" modifications. Recent nuclear-powered submarines, naval ships, and patrol aircraft all have been deliberately designed for better habitability to overcome past problems in crew motiviation, performance, and skill retention. Appropriate provision for the crew's comfort and well-being is one condition for making difficult environments less stressful. NASA's increasing attention to habitability, as in the conduct of studies on the use of free space and other factors in Skylab simulators at 1 *g*, is an encouraging development. Much more work will, of course, have to be done in the years to come.

PAST HABITABILITY PROBLEMS

A review of past manned space missions can be a starting point for identifying habitability issues that might be encountered in the future, although it must be recognized that long-duration flights will bring to the forefront additional problems, some perhaps in unanticipated areas. Consideration should be given, for example, to adaptation, long-term buildup of stress, and individual differences. The major habitability issues in the past have been the following:

Waste Management Equipment has been primitive, difficult to use (particularly in public) and a major source of complaint.

Food and Water Palatability and potability have been faulted, as have mechanical difficulties, associated with weightlessness, in preparation, eating, and drinking.

Sleep Difficulties have been encountered by most crews because of noise, lack of privacy, excitement, and inadequacies of the accommodations.

Human Engineering Some of the equipment associated with experiments, habitability, medical monitoring, and housekeeping have been difficult to use and the source of some operational problems.

Noise Noise has on occasion caused annoyance, hindered communications, and caused sleeplessness.

Lighting Optimal lighting is a continuing problem because of the high contrasts characteristic of space, electrical power limitations, and the engineering tradeoffs related to equipment selection.

Cabin Volume Both small and large volumes have caused problems such as restricted movements and cramping on the one hand and motion sickness on the other.

During the past two decades the number of experimental studies on confinement and habitability has been surprisingly large, especially when the expense and difficulty of such investigations are considered. They have been mainly in support of manned space and military programs. Based on present research and operational experience, some of the more significant topics are discussed below. It is not possible now to delineate precise characteristics of work and living space for long-duration flights as these will be mission- and system-specific.

SIGNIFICANCE OF SPACECRAFT VOLUME AND ITS CONFIGURATION

The amount of crew space and its form seem to be two of the more important considerations relative to habitability. There is evidence that performance degrades when individuals are confined for too long a period in too small a volume. This evidence comes from experimental or observational studies related to the behavioral aspects of confinement that have been done in experimental chambers, simulated vehicles, and operational vehicles. Data from 47 such studies are plotted in Figure 1 with volume per man as a function of duration of confinement; broad patterns of tolerance, based on impairment of function, are shown. As a point of reference the volume per man for Mercury was 54 ft^3; Gemini, 44 ft^3; and Apollo, 107 ft^3.

For good habitability and working conditions, Fraser (1966) suggests that about 125 to 150 ft^3/man of free space would be the minimum acceptable for 7 to 30 days and that thresholds of unacceptability would be about 40 ft^3 for 7 days and 85 ft^3 for 30 days. Feddersen (1966) recommends that sleep–rest stations should not be less than 300 ft^3/man and that work station volumes should be a function of operational requirements. Jones *et al.* (1966) take

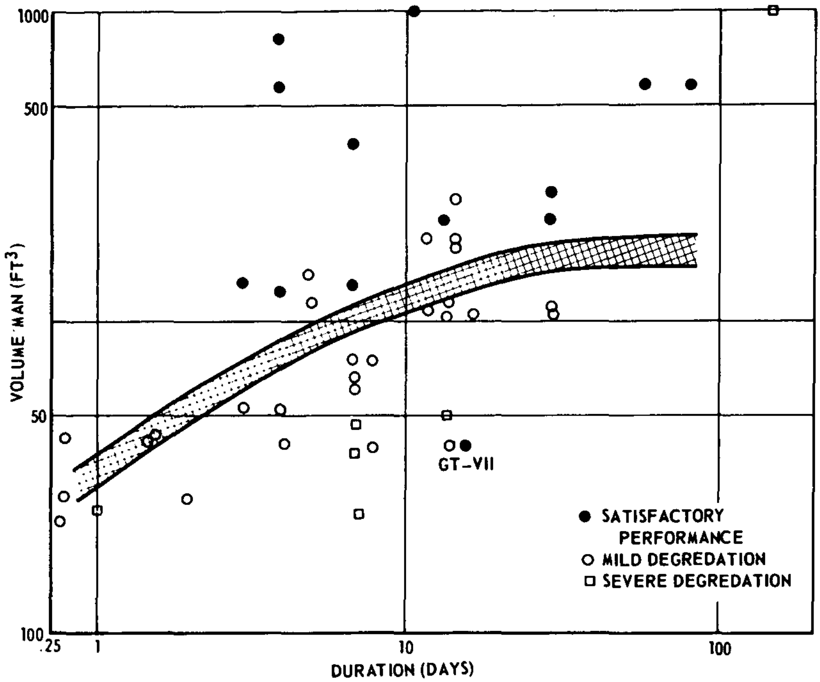

FIGURE 1 Volume per man versus mission duration up to 1966. (From Jones *et al.*, 1966, p. 49.)

a more extreme, austere position and suggest that volumes of 150 to 200 ft^3/man might be acceptable for 135 to 435 days for selected individuals. They caution, however, that extrapolations beyond 30 days are not too meaningful because present data are not representative of long-duration spaceflight. For durations of 300 to 400 days, appropriate guidelines would be (see Chapter 2) 200 to 250 ft^3/man, absolute minimum; 350 to 400 ft^3/man, acceptable; and 600 to 700 ft^3/man, optimal in the light of other requirements.

Jones and Prince (1964) caution that beyond 30 days factors other than volume, probably associated with isolation, appear to be the prime determinants of habitability. Fraser (1966) concludes that ". . . above the threshold of acceptability, volume is not a major constraint regardless of duration." For very long missions volume requirements are dominated by needs for recreational areas, food preparation, and work space. Finally, weightlessness might reduce problems found on earth, while artificial gravity might produce problems.

Data on configuration and on the way in which volume is used are less specific than those for volume both because there has been only limited research and because design is quite specific to the mission and crew functions. Some of the questions concerning configuration are

1. What are the relative advantages of compartmentalization versus openness?
2. Should the configuration be fixed or flexible or a combination of both?
3. What are the configurational issues when the same area must be used under a wide range of gravitational conditions from launch–re-entry loads through weightlessness and possible artificial *g*?
4. How does weightlessness affect the utilization of space? Is it more or less effective?
5. How can privacy best be achieved for individuals and groups without creating artificial social barriers or problems of safety or weight?
6. How can shirtsleeve and pressure-suited use of the same configurations be made compatible?
7. What are typical traffic and communication patterns, and how do these influence layout?
8. How can storage facilities be designed to allow appropriate access without interfering with crew comfort and use?

SPECIAL HUMAN-ENGINEERING REQUIREMENTS RELATING TO HABITABILITY

There is a long history of the application of human-engineering data and principles to the design of military systems. However, with past spacecraft primary attention was directed to crew-station functions and little systematic effort was directed toward producing a habitable environment. Some applicable habitability data exist, and requirements studies have been accomplished both independently and as a part of NASA and USAF design studies of long-duration-mission spacecraft (e.g., Price *et al.*, 1965).

Noise The problem of noise within spacecraft is not so much one of volume as of startle effects, background noise, and immediacy within a small area. The primary source of noise has been the environmental control system fans; secondary sources are the intermittent thruster firings and internal and external communications.

Fans are sometimes turned off at sleep periods, and crews have adopted the practice of sleeping at the same time to avoid disturbing each other. Similarly, mission control normally refrains from communications with the crew during these hours. In extreme cases, noise can make an environment intolerable, communications difficult, and mask indications of malfunction. On the other hand, there is evidence that too low a noise level and monotonous sounds also can create problems.

Research on the effects of noise on performance has been contradictory. For example, a study (Warner, 1969) of target detection using a 70 percent neutral off–on ratio for 80-, 90-, and 100-dB and no-noise levels, showed no deleterious effect of intensity on detection ability; instead there was a decrease in errors as intensity increased. Such an effect is probably due to the arousal value of noise. Also with greater sound intensities there was a greater flexibility of attention. There appear to have been large individual differences in reactivity to noise. Therefore noise control should consider the specific response patterns of the individual under varying noise levels.

In another study (Eschenbrenner, 1969) an operationally significant decrease in performance was obtained as a function of increasing intensity and variability in temporal pattern of noise. This study simulated the task involved in pointing a telescope at a spot on the earth's surface from a moving spacecraft. Continuous, periodic, and aperiodic noise levels of 50, 70, and 90 dB were used; these are within the range that has been present in spacecraft. Noise research suggests that the effects of noise depend on the difficulty of the assigned tasks and are more likely to interfere when the number of displays increases and greater flexibility of performance is required.

The Soviets have indicated concern over the effects of noise on space crews and have conducted a series of studies ranging in length from 8 h to 60 days in a closed cabin (Yuganov *et al.*, 1969). Results indicate that 60 to 65 dB for 60 days resulted in no significant long-term changes in function of the auditory system; the greatest effects occurred within the first few days. The subjects did not complain of effects on sleep or rest. The Russians concluded that noise levels should be specified for the various zones within the spacecraft, with the quiet areas not exceeding 40 dB. However, they felt a minimal level should be stipulated to avoid monotony.

Lighting Spacecraft lighting and illumination would appear to be relatively straightforward, yet they involve difficulties and complexities, many of them stemming from the strong light–dark contrasts typical in space, that have been only partially solved. Over-all systems anslysis should be brought to bear on this probem because individual design decisions made on a piecemeal basis are unlikely to take account of all the factors involved. For example, a "visual subsystem" concept was advanced during the development of Mercury which advocated that special attention be directed within a systems engineering framework toward *all* the elements that influence vision (Urmer and Jones, 1963). Optimal illumination in spacecraft during long-duration missions, in order to protect vision and minimize annoyances and performance problems arising from this source, will be important. Consideration should be given to the maintenance of day–night cycles through appropriate variation in lighting and the use of variable lighting to reduce visual monotony.

Mobility The ability of crew members to move about freely and easily within a spacecraft and to perform at a work station contributes to spacecraft habitability and facilitates job performance. Evidence from spaceflight and simulations points to many problems in this area. Simulations indicate that under conditions of weightlessness and partial *g* task performance requirements usually increase and work efficiency drops (Norman, 1969; Shavelson and Seminara, 1968; Wortz, 1969). These and other studies indicate that devices such as fasteners, hand holds, special shoes, equipment transporters and restraints at appropriate work stations are necessary to optimize crew mobility and proficiency inflight.

Communications Communication systems within the spacecraft and with the ground must provide mechanisms for exchange of information that sometimes might be private and other times public. An adequate communication system must avoid being a "big brother" but at the same time should allow individuals to be monitored or contacted without entering their private domain.

Sustenance and Sanitation Sanitary equipment, materials, and practices have been primitive at best, and long-duration missions cannot be accomplished without major improvements in this area: social and aesthetic considerations combine with basic issues of survival. Long-duration missions have many inherent characteristics that are stressful for man. Proper food, potable water, and adequate sanitary facilities can be used to ameliorate some of these stresses just as they have in the Antarctic, in submarines, and on long aircraft flights. A rather obvious principle is that, insofar as possible, conditions for normal living on earth should be duplicated. The problem in achieving this centers around weight limitations and the effects of weightlessness on almost all aspects of food preparation, eating, bathing, defecation, shaving, grooming, washing utensils, and housekeeping. Despite concentrated efforts to overcome the stubborn problems in this area, major developments are still needed in these programs which involve engineering, biomedical and social sciences, and, especially, human engineering.

Personal Protective Equipment Long-duration spaceflight would seem to require two distinct types of pressure suit, one for extravehicular activity (EVA), the other for intravehicular activity (IVA). The two types of suit have very different design characteristics. The IVA suit would be a constant-wear "flight suit" with maximum comfort when unpressurized and maximum mobility when pressurized. The EVA suit would be a sophisticated device, not normally worn for any length of time when unpressurized and marginally comfortable in that mode, and would afford maximum mobility and comfort when pressurized.

Although the current state of the art in EVA pressure suits allows adequate mobility at any reasonable pressure, the glove, especially, represents a serious design problem if higher operating pressures are desired. The primary advantage of higher operational pressures is that less time is required for transition from vehicle environment to ambient conditions. If the suit operates at considerably lower pressure than the vehicle, then time must be spent in eliminating dilutant gases from the body to reduce the probability of bends. The operating pressure of the suit becomes a determinant of the frequency of EVAs. If EVA operations are a regular and frequent portion of the mission, as would be the case in construction of a space station, then a common suit–vehicle operating pressure should be considered. An alternative to higher operating pressure might be to parallel undersea operations where EVA workers remain in a reduced pressure environment on 30- to 60-day shifts and return to the higher-pressure, mixed-gas environment for R&R (rest and recreation) periods. For a planetary mission, reduced pressure in the planetary landing module might be considered. However, if permanent sites are established with regular and frequent EVAs, the penalties of somewhat greater energy expenditure and suit weight would trade well against the increased EVA time.

The function of the IVA suit would be analogous to the little masks and oxygen supplies stowed in present jet passenger aircraft. The suit's emergency pressurization feature must be innocuous and not interfere with normal mission functions and crew comfort. Should an emergency depressurization or other contingency occur that required crew isolation from the cabin environment, the suits could be pressurized almost instantaneously (15 to 30 sec), possibly with "one-shot" multiple bladders, by donning a soft bubble helmet and hooking up to an emergency O_2 supply. The IVA suit might have further utility on re-entry, for the lower portion could be made capable of independent pressurization to aid in preventing hemostasis during re-entry and landing.

SCHEDULES FOR WORK, REST, AND RECREATION

Knowledge of man's ability to sleep in space is based on experience from the Mercury and Gemini programs in which astronauts slept in their seats and from Apollo which has a primitive "sleeping bag." In the latter case, many crewmen initially slept in a fetal position and felt ill at ease because there was no point of attachment; after a few days, however, they often slept as if floating in water, possibly hooking a foot around a piece of equipment to remain in one place. Sleep has been a problem on some flights, and Seconal has been used occasionally. There seem to be considerable differences among individuals and crews. In general, crews on later flights seemed to adapt better and after the initial excitement slept relatively well.

Long-duration flight might change this pattern considerably. For example, will the reduced gravitational state over long periods change an individual's need for sleep? Will the "Big Eye" phenomenon so common in wintering-over parties in the Antarctic be present in space? What are the implications of these possibilities for designing the spacecraft? There is no clear answer to these questions now. We can speculate that private sleeping quarters, with adequate noise and light control and appropriate attachment points for the individual, would be acceptable, but further investigations in space comparing several approaches are necessary.

Two related problems underlie the development of satisfactory schedules for work, sleep, and recreation. The first problem stems directly from the ongoing, hour-to-hour accumulation of fatigue or boredom resulting from the work situation. This problem is presumably alleviated by providing appropriate periods of relief from the demands of duty. The second problem stems from day-to-day repetition of work in the same environment. This presumably has a longer time constant and gives rise to the widely recognized need for complete breaks in routine through weekends off and vacations. The solution of the first problem lies in the basic design of the man–machine interface and in scheduling of work periods and sleep–rest periods that will minimize the production of fatigue and boredom and facilitate their dissipation once they have developed.

Sleep Requirements Although much remains to be learned about the "quality" of sleep in relation to its restorative powers, it is generally accepted that most people can function adequately with about six hours of sleep per day. There are, of course, substantial individual differences in the ease with which people fall asleep, their susceptibility to arousal by distractions both while going to sleep and during sleep, and the speed with which they return to normal functioning upon awakening. Considering all such factors, eight hours of rest time per day seems to be a widely employed figure.

Duty Period The primary factors to be considered in selecting the length of the duty period relate to the nature of the work required of the operator. Account must be taken of both the levels and varieties of the demands placed on him in carrying out his tasks. For example, some tasks involve only passive participation of the operator in that several minutes may elapse during which no event to which he must respond will occur; this sort of task is exemplified in radar watchkeeping. At the other extreme are tasks that require almost continual actions, e.g., manual control of the vehicle on re-entry. An important psychological factor underlying this distinction is the effect that these two different kinds of task have on the operator's level of alertness. Passive tasks produce or contribute to decreased alertness, whereas, at least up to some level of workload, active tasks tend to sustain or increase alertness. The variety of tasks—again up to some level of workload—also tends to promote alertness. On the other hand, overload and overarousal cannot exist long without detriment to performance. Even under the best of conditions attention fluctuates during a vigilance task.

The optimal length of duty periods has been investigated only within rather narrowly defined limits of quantity and type of tasks. Even though the work situation and the performance requirements may be specified exactly, substantive data about the appropriate length of duty periods are in short supply. When tasks are the same month after month, a work period that seemed to be suitable at the beginning of a mission may become intolerably long after a period of several months.

The use of shorter work periods would be advantageous in the event of greater requirement for man hours in a particular phase of the mission or in an emergency. The advantage would be realized during the period in which the individual is recovering from the increased demand. Specifically, a crew member may have gone with little or no sleep while coping with an emergency. He would probably find it much easier to maintain a satisfactory degree of alertness for a, say, 4-h duty period than a 10-h duty period until such time as he regains his pre-emergency status.

A thorough research program on work–rest schedules and workloads is required. Much of it could be accomplished on the ground.

Leisure-Time Activities It is well known, at least on a biographical basis, that many people are able to function satisfactorily for many months and even years without weekend or vacation breaks. Motivation seems to be the critical ingredient. Although the levels of motivation of astronauts are known to be extremely high, this should not be permitted to downgrade the importance of making adequate provision for recreation as a technique for reducing the impact of being faced with the same basic situation month after month. Similarly, it would seem unwise to assume that the astronauts would differ from the remainder of the population in their responses to long periods with little or nothing of interest to do. Since manning requirements must be based on provision for adequate man hours during the critical phases of the mission, demands on the available manpower at other times could be rather light. It is unlikely that data relevant to the effects of unoccupied time will be acquired from short-duration flights in which every minute, typically, is committed unless equipment problems in Skylab, for example, should prevent certain experiments and create unexpected leisure time.

The primary approach to the solution of the problem of provision for leisure-time activities involves careful analysis of the tastes and distastes of individual astronauts and their full participation in the final selection of materials and equipment. The range of possible materials and equipment has been reviewed and reported on in depth by Eberhard (1967) and Fraser (1968b). Because some of the more popular forms of recreation are reading, music, and television—with accompanying requirements for materials, equipment, and power—a number of the problems in this area may require technological solutions, e.g., the development of highly compact but enjoyably legible books. Perhaps Fraser (1968b) has best summarized recreation requirements by stating that they should not be merely a way of filling in time but should be used creatively for self-development that is integrated with the needs of the total mission. He also emphasized that exercise needed medically could be used for recreation.

SPECIAL RESEARCH REQUIRED ON HABITABILITY REQUIREMENTS

The preceding discussions identified a number of problem areas affecting habitability, some based on spaceflight experience. It is clear that there are many unknowns regarding the interaction between spacecraft design, the environment, mission duration, and man's well-being. The following are needed to help to enlarge our data base:

Integrative Approach The elements of habitability are complex and pervasive for selection, training, design, and operational practices, as illustrated in Figure 2. All these elements and others (known and unknown) interact complexly to determine habitability. These suggest that habitability research should have a programmatic orientation to identify what is known, what we need to know, and what equipment must be developed and tested. This further implies development of criteria of habitability, identification of factors influencing habitability, and parametric and system studies, culminating in systematic verification in space. In short, a holistic, systematic approach appears most likely to assure that man will have a habitable environment.

Research Ground-based studies can and should provide the building blocks for formulating habitability research in space, and, for reasons of cost and flexibility, they should be carried as far as is reasonably practicable. However, most elements of habitability must consider weightlessness as a function of time as well as the special motivational and stress factors in space. Thus, in addition to the need for verification in space of ground-based results, an inflight development program for habitability will be required. Two inflight habitability experiments are approved for Skylab: Habitability/Crew Quarters (M-487) and Time and Motion Study (M-151). These represent only the beginning of what must be a long-term, systematic effort.

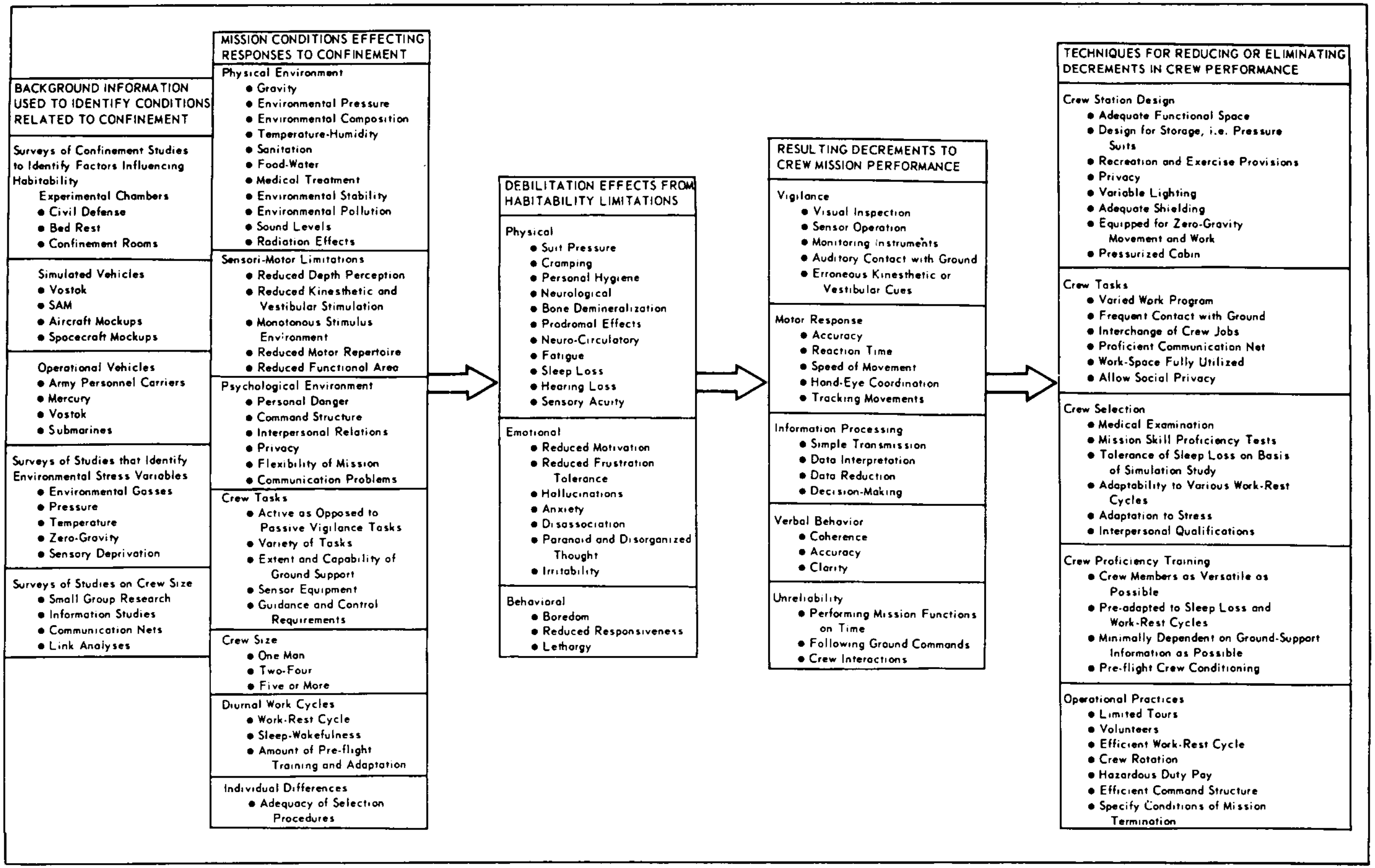

FIGURE 2 Volumetric, crew, and configuration considerations for spacecraft cabin design. (From Jones *et al.*, 1966, p. 51.)

Empirical data are needed to complement astronaut reports. Comparative studies to test habitability are advisable when variations are made in spacecraft layout and architecture, with a sufficient number of representative subjects so that results can be generalized.

PERFORMANCE SKILLS ON LONG-DURATION MISSIONS

The intricate and critical tasks that the crew must perform at re-entry or, in the case of a planetary mission, in landing on a planetary surface after a journey of many months raise the problem of maintaining high skill levels in these tasks during the long intervening period. In current space operations, rendezvous, lunar landings, and other piloting tasks can be practiced in simulators to within a few days of the launch. Thus the pilot's skill is at or near its peak when these operations must actually be carried out. Unless on-board simulation facilities are provided, a similar opportunity for practice of critical operations will not be available on long-duration missions. To what extent will a lack of "warm-up" training present a problem?

The bulk of research on retention has emphasized verbal rather than psychomotor skills, short rather than long retention intervals, and simple rather than complex tasks. Only recently has there been emphasis on long retention intervals for complex psychomotor tasks. This recent effort has had its impetus from the space program.

A comprehensive review of long-term skill retention was completed by Naylor and Briggs in 1961. From this and other sources it is possible to summarize the significant factors related to retention: extent and type of original learning, type of task (difficulty and organization), characteristics of intervening activity, length of retention intervals, and method of measuring retention.

The most directly applicable research for skill maintenance during long-duration missions has been done recently for continuous psychomotor tasks. Complex discrete motor tasks (procedural) comparable with those found aboard spacecraft have been examined for retention intervals only up to four weeks (Naylor *et al.*, 1962). Diagnostic and decision-making functions have not received any significant attention, probably because they are difficult to define and categorize. Most importantly, none of the studies has considered the combined stresses of space. For example, what happens to sensory perception, particularly the vestibular, kinesthetic, and somatic sensors, as a function of long exposure to weightlessness? If changes occur, what impact do they have on retention? What about warm-up effects as a function of different force fields and changes in proprioceptive feedback?

The three most applicable studies on psychomotor performance involved the following:

Retention Intervals up to 24 Months A task simulating a radar intercept mission was used with no-practice retention intervals of 4, 9, 14, and 24 months. Virtually no loss occurred up to 14 months, and, after 24 months of no practice, complete recovery occurred during the first 20 min of relearning. Differences among subjects in initial skill levels was the major variable and correlated in the 0.80 to 0.90 range with subsequent performance. The authors concluded that original performance level rather than the retention interval was the more important operative factor (Fleischman and Parker, 1962).

Retention Intervals up to 200 Days A high-fidelity simulator duplicating the complex image–motion compensation task which nulls out motion between a moving spacecraft and a ground target through variable cloud cover was used with no-practice retention intervals of 30, 90, and 200 days. Little loss occurred up to 90 days, but after 200 days 15 remedial trials were required to regain initial skill. The loss in mean time on target rose by a factor of between 5 and 7 from 30 to 200 days, depending on the level of difficulty. The authors concluded that on-board training devices would be required for this task for retention intervals approaching 200 days (Youngling *et al.*, 1968).

Retention Intervals up to 88 Days A high-fidelity three-man simulator duplicating a lunar-landing mission was used with the crews returning after a 7-day integrated mission for no-practice retention intervals of 53 and 88 days. The results obtained for the 53- and 88-day intervals did not differ significantly. Flight control and switching tasks showed no significant decrement when related to performance on the 7-day mission. The authors concluded that losses in skill were smaller than anticipated and were closely related to training levels (Grodsky *et al.*, 1966).

SKILL RETENTION

The major concern here is the impact of intervals up to 700 days on retention of previously learned tasks. A complicating element is that most tasks will have been learned on simulators whose fidelity will be less than perfect, particularly in terms of environmental effects. Many other tasks such as those involving contingencies will not have been considered directly in the training program. Since each space mission tends to be unique and crews probably will go on only one long-duration mission, one mission cannot be used to train for the next. Thus, maintenance of skill is complicated by transfer issues and environmental stress as well as possible interfering (or even facilitating) effects of intervening activities before and during the mission. Another consideration is how degradation of crew performance may affect mission success. Some system tasks are less sensitive to degradation than others and can tolerate a considerable reduction in crew performance without seriously affecting mission accomplishment. Pilots describe aircraft that are "forgiving" because performance errors tend not to be critical. Some tasks aboard spacecraft must be performed correctly the first time, while others can be repeated without affecting safety if initial performance is poor.

The mission tasks that would seem most susceptible to skill loss are planetary landings and the return to earth. However, the precise method for their accomplishment will be defined during system development. It is possible that the return from a planetary voyage will terminate in earth orbit: a space shuttle would rendezvous with the spacecraft and return the planetary crew to earth, avoiding the need for their performing precise tasks under acceleration loads after long periods of weightlessness.

Examination of crew functions aboard present spacecraft indicates that the most important functions involve diagnosis and decision-making. This is a generalized skill in which the individual perceives a large number of factors bearing on the state of the system and operational situation and evaluates them in terms of his past experience and their impact on mission success. Information needed for decision-making may involve verbal materials subject to rapid decay. Task interference aboard the spacecraft also could play a part in skill loss because many tasks tend to be similar yet have critical differences that might be susceptible to negative transfer effects. Examples are similar tracking systems with reversed control display relationships or the same type of warning lights that require different responses depending on their location. Sleep loss, extended work periods, reduced motivation, and environmental effects might also contribute to skill loss.

In sum, it seems that continuous psychomotor tasks and complex decision-making represent the greatest potential problems for skill maintenance during long-duration flight. If the task is a one-time event, if no warm-up is possible, and if performance of this task is not required until well into the mission, then skill loss is more apt to be an issue. Assistance in decision-making would be obtained from mission control (limited only by reaction time and communication capabilities). However, continuous psychomotor tasks do not lend themselves readily to assistance from others.

METHODS FOR IMPROVING SKILL RETENTION

Present technology has a number of mechanisms that might be used to overcome skill loss from anticipated sources. However, disruptive effects of the environment are another issue, and their impact could be significant. The following approaches to reduce skill loss are suggested:

System Design System functions that are mission-oriented and require high levels of error-free performance should be automated, especially if they must be performed properly on the first trial.

Initial Training Extensive practice can be directed to mission-critical tasks assuming that overlearning will delay decay of skills and the disruptive effects of the environment. It has been shown that additional training can improve retention of less organized tasks almost to the level of that of more highly organized tasks (Naylor *et al.*, 1962). Augmented feedback during initial learning also can aid retention (Lincoln, 1956). However, this training approach has its limits because of time, cost, and problems of the fidelity of the simulation.

On-Board Training Simulators can be used for "peaking" continuous and discrete psychomotor performance, and system operation can be reviewed using rehearsal or even traditional classroom approaches augmented perhaps by on-board data display systems. On-board training equipment adds weight to the spacecraft and contributes to equipment unreliability; it might be justified for some functions especially if it is well integrated into existing equipment.

Performance Aids These have been highly developed for maintenance tasks and have great utility on board spacecraft. They are audiovisual materials that include job guides, checklists, trouble-shooting aids, and integrated schematics. They can be stored on high-capacity films and tapes and called up selectively for use.

Ground-Control Assistance Previous space missions have demonstrated the desirability of calling on ground-based specialists to help solve problems in space. When feasible, this reduces considerably the amount of information individual crewmen must retain. However, there can be transmission lags up to 10 min in deep space.

Research on Task Retention Research is needed to identify better the decay characteristics of learned tasks as a function of long retention intervals and the space environment. The research should emphasize: (a) decision-making and diagnostic tasks; (b) transfer effects as they influence retention (since tasks are learned in a simulator); and (c) environmental stresses, particularly weightlessness. As indicated earlier, there are several impediments to such research. For example, although the retention characteristics of continuous psychomotor tasks are well known (i.e., any organized task learned to a high proficiency is retained well particularly if a brief warm-up is possible), the impact of weightlessness is not known. This requires inflight research supported by ground-based studies. Other impediments include the inability to define crew tasks for long-duration missions now, and the fact that in ground-based studies control of intervening activities is difficult and retrieval of subjects or retention measurements may be difficult because of long intervals.

Our greatest gap in knowledge concerns the retention of diagnostic and decision-making skills which would seem to be the predominant functions for future men in space. Research is needed in this area in conjunction with the development of techniques of the type described above for reducing skill loss.

OPERATIONAL RESEARCH

It is clear that much of the knowledge on which new operational procedures are to be based must be developed from operational experience. Ground research programs can isolate elements of the total problem for detailed scientific study; they must be complemented by objective data from the ongoing operations. The NASA flight reports and, more importantly, the effective operations of the vehicle, demonstrate the extent to which analysis has been built into flight operations. This analysis, however, has tended to be least complete with respect to crew performance. Given the effectiveness of current spacecraft systems, future missions may involve greater unknowns for the crew than for the vehicle. Thus, emphasis must be given to operational evaluation of the human elements of the system. The following procedures are suggested:

1. All crew members, both ground and flight, should be evaluated. Too frequently attention has focused on the flight crew to the exclusion of ground-crew members. While it is the flight crew who will be most affected by the special features of long-duration flight, the crew of the mission-control center will also face special problems and quite possibly may be overstressed during the course of the mission. Further, evaluations of all the major members of the ground crew would help to desensitize the flight crew: they will not be the only "guinea pigs." Rather, all individuals who have a critical part to play in the mission, as well as the mechanical components of the system, would be under regular evaluation.

2. Objective procedures must be developed to evaluate these human components in the system. Too frequently the methods by which the crew are evaluated are unstated and subjective. Only by developing objective measures can data be collected that will be maximally useful in assessing the effects of different approaches to crew selection, crew training, and crew work schedules. Such measures should be depersonalized: emphasis should be on the effectiveness of the system as a whole, not on the individuals. These objective measures should be collected and evaluated by a special analysis group, and the evaluation procedure should be separated as much as possible from the regular administrative procedures within the Manned Spacecraft Center. Careful provision must be made for privacy, but the need for privacy must not become a basis for failure to make objective measurements. It should be possible for the Manned Spacecraft Center to provide for an operational analysis group of its own, with capability both to collect and protect data.

3. Since much of the evaluation will involve performance, it is important that specialists in human performance research be represented on the analysis team. In order to permit scientists to analyze the findings of these studies and to take advantage of their knowledge in planning data collection during flight, a different system than that presently utilized for flight experiments will probably be required. The present system in which senior scientists propose flight

experiments which, if approved by NASA, are developed by the investigator with the support of appropriate engineering departments at the Manned Spacecraft Center is not well adapted to the needs of operational human performance research. Rather, appropriate outside experts should be retained as consultants to work through an adequate local staff of human-factors specialists. Such a system may also help to assure that data will be handled so as to ensure the privacy of both the flight and ground crew while permitting adequate evaluation of performance.

One example of the types of operational measure that are currently not being fully exploited but that could be quite useful in the development of operational procedures for long-duration flights are techniques such as those used in the Tektite studies of operations. In this program a television record of each crew member's location and activities was kept throughout the mission. In the spacecraft either television or time-lapse photography could provide the same kind of data. These records would permit time-line analysis of crew activities and information on methods of locomotion, use of "seats" and "beds," physical problems in the operation of equipment, and similar factors.

EVALUATION OF FLIGHT PERFORMANCE

The major factor in the spacecraft "shirtsleeves" environment that would have a direct effect on the performance of operational tasks is the absence of gravity (Chiles, 1966, 1967; Finley *et al.*, 1969). However, the lack of problems on space missions to date suggests that the astronaut can carry out a variety of motor functions in a completely acceptable manner. Experiments planned for Skylab (e.g., experiments M-151, M-171, M-508) should provide more quantitative information on the effect of 0-*g* on motor tasks.

Other factors that might affect the efficiency of performance would be secondary to medical and behavioral changes resulting from long-term exposure to the spaceflight environment. A very significant—but virtually unknown—area derives from the following, as yet unanswered, question. Do subclinical changes in man's physiology–biochemistry–neurology have implications for performance? The innumerable corollaries of this question have received only superficial attention in the context of ground operations—none in space. A reasonable speculation would be that, because of the intensive training of the astronaut and the attention given to the human engineering of space systems, any minimal changes in biomedical factors would have only minor impact on the ability to perform under normal operating conditions. But the impact on performance capabilities of an emergency, placing unusual demands on the astronaut for a sustained period of time, is not so clear. Any conditions leading to fatigue or sleep loss might very well combine with minimal biomedical encroachments and result in an unsafe operating situation. Minor illnesses could compound the problem. It has been speculated that man will require less sleep in space. If correct, it could mean that less sleep is needed to maintain psychological status at full performance capability; it could also mean some resultant loss in his readiness to perform—especially with respect to his reserves for meeting emergencies.

An objective determination of man's performance capabilities and limitations in the space environment would seem mandatory prior to embarkation on extended space missions. Even if it is assumed that man can provide an objective assessment of his own capabilities, possible changes in higher processes on which such an assessment would depend might alter his ability to analyze his own performance status and would make his judgment suspect.

There are at present no approved NASA programs for obtaining information on performance capabilities, other than motor performance, which could serve as valid bases for extrapolation to long-duration spaceflight. The only information available is that astronauts have apparently performed their assigned duties satisfactorily in past missions. If it could be specified that future demands placed on man by these duties will never significantly exceed those met previously, then ordinary operational experience would serve as an adequate basis for extrapolation. However, because of the care with which space systems are designed, the skill levels achieved by the highly selected astronaut population through intensive training programs are not challenged under normal operating conditions. Hence, the use of existing criteria based on the performance of operational tasks is analogous to the use (in an educational situation) of an examination on which every one in the class turns in a perfect paper; the examination establishes that a specified amount of information has been mastered but provides no information about potential weaknesses of the student (or of the instructional program). In other words, satisfactory performance of operational tasks affords little more than a pass–fail criterion at some (unspecified) point on the continuum of the man's performance capabilities. We would only know that his performance was not poorer than this unspecified level.

The most valuable contribution to be made by ground or orbital research toward the specification of the impact of the space environment on performance capabilities would be the development of techniques that would permit quantification of the precision with which operational tasks are performed. Only when such measures of precision are available will it be possible to extrapolate with confidence to tasks or situations that lie any significant distance beyond the boundaries defined by existing tasks and conditions. And the measurement techniques developed would be of inestimable value throughout the field of human factors.

RECOMMENDATIONS

1. In view of the greatly expanded time dimension of long-duration missions and the increased complexity that will of necessity be added to the spacecraft, its internal environment, and operational procedures, it is recommended that a systems-analysis approach be applied to study and redefine the human-factors requirements of the spacecraft, of the flight and ground crews, and of ground support and mission control. All the elements of the long-duration mission, including its preflight and postflight portions, should be considered together as a totally integrated and mutually reinforcing system.

2. Because of the length of the mission and, in the case of planetary missions, the extreme distance of the spacecraft from ground-control command, program decisions relevant to human-factors requirements should be redefined with respect to on-board maintenance, mission center command and control philosophy, inflight scientific research, and composition of the flight and backup crews.

3. Task allocation for both normal circumstances and emergencies, and determination of optimal schedules for work, sleep, and recreation are critically important to crew effectiveness and mission success. Systematic ground-based research, including simulations, and accumulation of experience from precursor spaceflights will be required to obtain the information that must go into these decisions.

4. All communications between the spacecraft and the outside world will necessarily be governed by mission control. Careful, imagi-

native study should be given to assure that this sensitive and crucial role of mission control is supportive of crew effectiveness, morale, and motivation.

5. Systematic research on spacecraft habitability is needed, especially with regard to capsule volume, configuration, and noise as these relate to work, mobility, exercise, recreation, and sleep.

6. Research is strongly recommended to identify better the decay characteristics of learned tasks as a function of long retention intervals and the space environment. The research should emphasize decision-making and diagnostic tasks, transfer effects as they influence retention, and the effects of stress, particularly weightlessness. In conjunction, existing techniques to reduce or compensate for skill loss should be evaluated for relevance to the spaceflight situation and new ones developed and tested.

7. Objective methods to measure performance precisely, particularly higher-level performance, are not available. Consequently, it is not possible to extrapolate with confidence to tasks or situations that lie any significant distance beyond the boundaries defined by existing tasks and conditions or even to have more than a gross knowledge of how well existing tasks are performed. The availability of proved methods of this kind would have wide application and would seem mandatory for long-duration missions. Initiation of research is urged.

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